TECHNICAL SUMMARY REPORT

BEST MANAGEMENT PRACTICES FOR GREENWASTE COMPOSTING OPERATIONS: AIR EMISSIONS TESTS VS. FEEDSTOCK CONTROLS & AERATION TECHNIQUES

CONDUCTED BY
CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD
WITH SUPPORT FROM
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

July 29, 2003

S T A T E O F C A L I F O R N I A

Gray Davis
Governor

CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD

Linda Moulton-Patterson
Board Chair

Steven R. Jones
Board Member

Jose′ Medina
Board Member

Michael Paparian
Board Member

Cheryl Peace
Board Member

Carl Washington
Board Member

Mark Leary
Executive Director

California Integrated Waste Management Board
1001 I Street
P. O. Box 4025
Sacramento, CA 95812-4025

Publication # IWMB-2008-016

Prepared as part of contract # IWM-C-0126 totaling $74,890

Author: Brenda K. Smyth, Senior Integrated Waste Management Specialist
Organics and Resource Efficiency Branch

Peer Review: Chuck E. Schmidt, Ph.D., Environmental Consultant
Alan Glabe, Ph.D., California Integrated Waste Management Board

TABLE OF CONTENTS

INTRODUCTION

This Technical Summary Report documents area source emission tests conducted by the California Integrated Waste Management Board (CIWMB) and supported by the South Coast Air Quality Management District (SCAQMD) on greenwaste composting operations. The tests were conducted to evaluate Best Management Practices (BMP) for greenwaste composting operations that would result in reduced air emissions. Test procedures were designed to evaluate feedstock blends and aeration techniques and to determine how changing these variables affects air emissions from the compost. In addition to feedstock blends and aeration techniques, there are numerous operating variables in the composting process that can affect air emissions such as temperature, moisture, pH, and pile shape and size. However, due to the difficulty of isolating variables, the costs associated with testing source emissions, and limited funding, feedstock blends and aeration techniques were chosen as common variables that greenwaste composters could control. An effort was made to hold all other variables constant as much as possible.

DESCRIPTION OF TESTS

The tests were hosted by Tierra Verde Industries (TVI), a greenwaste composting facility located in Irvine, California. TVI constructed custom windrows and followed prescribed operating procedures during the test to simulate various composting environments. Emissions testing were conducted on four standard sized, full-scale windrows. Figure 1 shows two of the test windrows. Feedstock materials for the windrows were prepared and weighed on October 25, 2002; windrows were constructed on October 26, 2002. Table 1 provides a description of each windrow. (Note that the test conditions are not reflective of TVI's normal operation and therefore emission results from the tests have no relationship to expected emissions at the TVI facility.)

Figure 1: Two test windrows at Tierra Verde Industries

Carbon-to-Nitrogen Ratio
Test variables included feedstock blends, aeration techniques, and test pile age. Feedstock blends were controlled by the amount of grass clippings (curbside greenwaste) and the amount of woody waste (some grass clippings, but mostly leaves, brush, and wood) that were mixed together before composting. Feedstock blends were characterized by measuring the carbon-to-nitrogen ratio (C:N) in the mixture of materials. Two alternatives of feedstock blends were tested: high C:N materials and low C:N materials. To achieve a high C:N blend of materials, TVI mixed predominately woody waste with some grass clippings. To achieve a low C:N blend of materials, TVI mixed predominately grass clippings with some wood waste.

Aeration
Two aeration techniques were evaluated during the tests, static pile and turned pile. Two static pile windrows were formed to standard, full-scale dimensions and then were allowed to self-aerate by natural convection only for the entire composting life cycle. Turned pile operation involved two windrows that were constructed to the same shape and dimensions as the static pile windrows but were turned with a Scarab to provide aeration. The turned windrows were turned approximately three times per week depending on temperature. Due to the decrease in windrow temperature that occurs during turning, turnings were conducted when windrow temperatures were high enough to withstand turning and still maintain 131°F needed for pathogen reduction requirements.

Figure 2: Scarab turning test windrow.

Pile Age
The four test windrows were allowed to remain in place for a nominal 100-day life cycle. Area source emission tests were concentrated on the initial phase of composting where emissions were expected to be higher. Since life cycle analysis of emissions was not the intent of these tests, not enough data was collected to complete an accurate analysis of how emissions change over the entire 100-day compost cycle. Rather, emissions from the first week of composting (Day 3 and Day 4) can be compared to emissions from the second week of composting (Day 11 and Day 12).

Table 1: Description of Test Windrows				
Designation	***Aeration Technique***	***Description***	***Feedstock Blend***	***Description***
Row 1	Static	Not turned; natural convection only	Low C:N	Greenwaste, grass clippings
Row 2	Turned	Mechanically turned; Scarab, ~3 times/week	Low C:N	Greenwaste, grass clippings
Row 3	Static	Not turned; natural convection only	High C:N	Woody waste
Row 4	Turned	Mechanically turned; Scarab, ~3 times/week	High C:N	Woody waste

Windrow Dimensions and Weight

The four test windrows were constructed to approximately the same dimensions in rough trapezoidal shapes that were 105 to 120 feet long, 13 feet wide, and 6 feet high. Feedstock materials were blended together to form two compost windrows with high C:N ratios and two compost windrows with low C:N ratios. Feedstock materials in the blends included: grass clippings from curbside collection, fines collected after grinding curbside greenwaste, mulch-type materials from landscapers, and wood waste. Prior to construction of the windrows, the feedstock blend for each windrow was weighed at the scale house. The two windrows with low C:N ratios were comprised of roughly 50 percent curbside fines, 40 percent grass clippings, and 10 percent wood waste. The two windrows with high C:N ratios were comprised of 50 percent landscapers mulch materials and 50 percent wood waste. The total amount of material in each of the four windrows weighed between 146,080 and 147,610 lbs, or approximately 73 tons. CIWMB staff observed the construction of the test windrows on October 26, 2002. Figure 2 below shows information on the dimensions and the amount of material placed in each windrow.

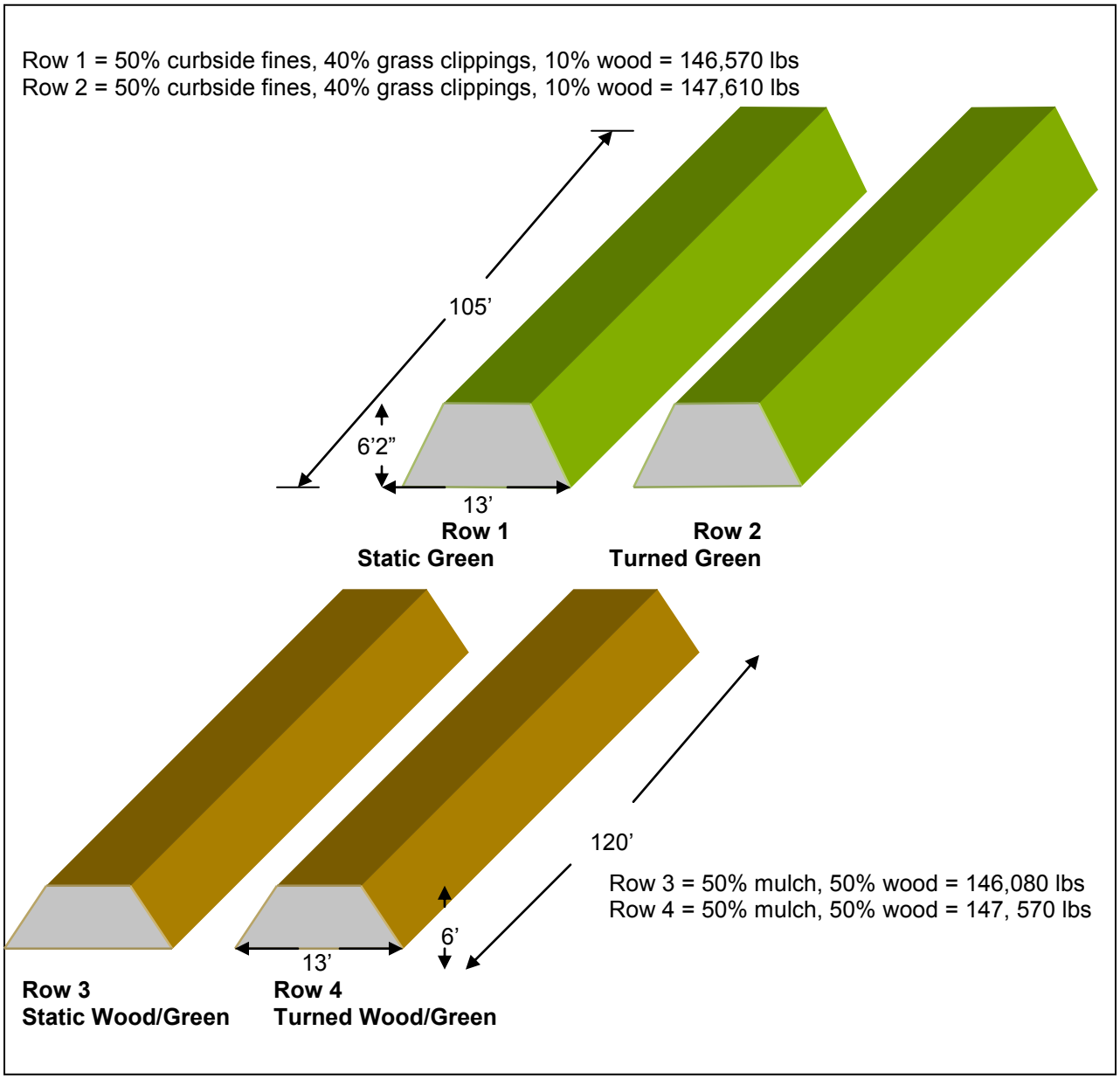


Figure 3: Diagram of Windrow Dimensions and Amounts of Materials

Emissions Testing

Source emissions tests were conducted to determine if there is a reduction in emissions from greenwaste compost windrows by controlling feedstock blends (high vs. low C:N ratio) and aeration techniques (static vs. turned). All four windrows were tested at multiple locations during the first week of composting and during the second week of composting. Tests were conducted on Day3/Day 4 and Day 11/Day 12. Each windrow was tested at six locations, which included the windrow ridge-top or vented locations and windrow sides or non-vented locations. Ammonia, volatile/semi-volatile organic compounds (VOC/SVOCs), and odor were sampled to describe air emissions from the test windrows. The air emission tests were performed by Dr.

Chuck E. Schmidt, an independent consultant contracted with CIWMB, and samples were analyzed at independent laboratories. The SCAQMD also provided laboratory analyses for some of the air emission samples including fixed gas analyses on the windrows and for performance evaluation samples. Mike Garibay, SCAQMD senior air quality engineer, and other SCAQMD staff observed parts of the testing.

Figure 4: Isolation flux chambers test emissions at multiple locations.

Solids Testing

Compost materials were tested in the windrows to determine the C:N ratio of the feedstock blends and to measure other physical characteristics of the solid materials such as bulk density, moisture content, total solids, and volatile solids. All four windrows were tested at multiple locations during the first week of composting, during the second week of composting, and at the end of the composting life cycle. Tests were conducted on Day3/Day 4 and Day 11/Day 12 and Day 101/102. Each windrow was tested at four locations spaced evenly across the length of the windrow. In addition, a Solvita Maturity Index was performed on end-of-life-cycle product (Day 101/102) to determine relative completion of the composting process for each of the four test windrows. Results from the solids testing were used to track the changes in the characteristics of the compost materials across the entire life cycle.

TEST PROTOCOL

Prior to conducting the tests at TVI, a test protocol was developed. The test protocol clearly identified the purpose of the tests in evaluating Best Management Practices (BMPs) for greenwaste composting operations, the test variables to be considered and how those variables would be adjusted, the sample schedule, test methodology, and laboratory analytical methods. CIWMB conducted meetings with SCAQMD staff in October 2002 and submitted the test protocol on October 15, 2002, prior to the start of the tests, for their review. SCAQMD reviewed and approved the test protocol on October 25, 2002. The test protocol included the following constituents that were measured to determine if the BMP variables had an effect on emissions.

- Volatile Organic Compounds (VOC) – sampled using USEPA isolation flux chamber, analyzed by trap/canister collection and AQMD Method 25.3 (GC/FID)

- Ammonia (NH_3) – sampled using USEPA isolation flux chamber, analyzed by acid impinger collection and SCAQMD 207.1 (USEPA-CTM-027; ion chromatography)
- Odor – analyzed by bag collection and olfactory analysis; ASTM E679-91
- VOC Speciation – sampled using USEPA isolation flux chamber, analyzed by USEPA Method TO-15 (GC/MS)
- In-situ oxygen (oxygen inside the windrows) – analyzed by bag or canister collection and fixed gas analysis by ASTM D1946 (GC/TCD)
- Feedstock blends and compost quality – analyzed by measuring the C:N ratio of materials and other solids physical properties.

Table 2a and 2b provide a detailed sample schedule and test methodology that was used for the BMP tests.

Table 2a: Sample Schedule and Test Methodology

Test Conditions				Measurements										
Compost Age	***Feedstock***	***Description***	***Oxygen***	***VOC****	***NH_3***	***Odor***	***O2 - 4 locations***	***C:N***	***Tot Solids***	***Vol Solids***	***CO2 - 4 locations***	***Bulk Density***	***Temp - 4 locations***	***Moisture***
				SCAQMD 25.3	SCAQMD 207.1	ASTM	ASTM E-679-91	EPA 990.3	EPA 160.3	EPA 160.4	EPA 3C			ASTM 2216
Day 3, 4	Low C:N	greenwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 3, 4	High C:N	greenwaste + woodwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 3, 4	Low C:N	greenwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 3, 4	High C:N	greenwaste + woodwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 11,12	Low C:N	greenwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 11,12	High C:N	greenwaste + woodwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 11,12	Low C:N	greenwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 11,12	High C:N	greenwaste + woodwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
QC Samples				8	8	4	4	4						
Total Number of Samples				56	56	12	32 min	12	10	10	48 min	8	32 min	8

Table 2b: Product Quality Sample Schedule & Test Methodology

Test Conditions				Product Quality Measurements					
Compost Age	***Feedstock***	***Description***	***Oxygen***	***C:N***	***Bulk Density***	***Moisture***	***Tot Solids***	***Vol Solids***	***Solvita Maturity Index***
				EPA 990.3		ASTM 2216	EPA 160.3	EPA 160.4	
Finished Product	Low C:N	greenwaste	Static	X	X	X	X	X	X
Finished Product	High C:N	greenwaste + woodwaste	Static	X	X	X	X	X	X
Finished Product	Low C:N	greenwaste	Turned	X	X	X	X	X	X
Finished Product	High C:N	greenwaste + woodwaste	Turned	X	X	X	X	X	X
Total Number of Samples				4	4	4	4	4	4

Low C:N = greenwaste; High C:N = greenwaste + woodwaste
Static = natural convection, non-turned static windrow
Turned = windrow that is turned 1-3 times/week with Scarab-type equipment
V = Vented; NV = Nonvented
USEPA TO-15 as VOC speciation at one (1) location per windrow per day; 8 total.
Note 1- the odor samples are to be collected from the flux chamber and not in-situ in the pile like the oxygen samples.
Note 2- SCAQMD typically requires duplicate 25.3 sample collection.

TEST RESULTS

Table 3 through Table 7 show the test results. Samples were taken on October 29, 2002 (Day 3), October 30, 2002 (Day 4), November 6, 2002 (Day 11), November 7, 2002 (Day 12), February 4, 2003 (Day 101), and February 5, 2003 (Day 102). Test results are shown by either calendar date or compost age, e.g. Day 3. All of the solids data and the compost quality results are shown in Table 3. The air emissions or flux data are shown in Table 4 for the static windrows tested on Day 3, Table 5 for the turned windrows tested on Day 4, Table 6 for the static windrows tested on Day 11, and Table 7 for the turned windrows tested on Day 12. For the air emission data, the CIWMB contractor Dr. C. E. Schmidt prepared a Technical Memorandum, which is included in the Appendix of this Technical Summary Report. Although the air emission data is summarized here in Tables 4 through 7, additional details are available in the Appendix. Also included in the Appendix are sample data sheets, lab data sheets, and chain of custody for the solids samples.

Table 3: Summary of Solids Sample Collection Data (Days 3, 4, 11, 12, 101, 102)											
Date	Time	Age	S or T	C/N Ratio	Sample ID	C/N	Bulk Density (lb/cy)	Moisture (wt%)	Tot Solids (mg/kg)	Vol Solids (mg/kg)	Solvita
10/29/2002	842	3 Day	Static	Low	SPL1	20	400	32	620000	410000	
10/29/2002	852	3 Day	Static	Low	SPL2	16	330	42	560000	370000	
10/29/2002	900	3 Day	Static	Low	SPL3	18	380	37	610000	360000	
10/29/2002	925	3 Day	Static	Low	SPL4	20	610	52	440000	260000	
					Ave	**18.5**	**430**	**41**	**557500**	**350000**	
10/29/2002	945	3 Day	Static	High	SPH1	51	510	55	480000	440000	
10/29/2002	950	3 Day	Static	High	SPH2	59	580	60	480000	450000	
10/29/2002	1011	3 Day	Static	High	SPH3	56	570	56	490000	450000	
10/29/2002	1020	3 Day	Static	High	SPH4	51	610	51	550000	500000	
					Ave	**54.25**	**568**	**56**	**500000**	**460000**	
10/30/2002	848	4 Day	Turned	Low	MPL1	26	520	50	540000	350000	
10/30/2002	854	4 Day	Turned	Low	MPL2	25	420	50	550000	350000	
10/30/2002	858	4 Day	Turned	Low	MPL3	26	450	48	600000	370000	
10/30/2002	900	4 Day	Turned	Low	MPL4	28	440	44	570000	360000	
					Ave	**26.25**	**458**	**48**	**565000**	**357500**	
10/30/2002	905	4 Day	Turned	High	MPH1	64	430	48	1200000	1100000	
10/30/2002	905	4 Day	Turned	High	MPH2	65	470	38	640000	600000	
10/30/2002	911	4 Day	Turned	High	MPH3	100	410	31	660000	610000	
10/30/2002	915	4 Day	Turned	High	MPH4	68	460	35	580000	540000	
					Ave	**74.25**	**443**	**38**	**770000**	**712500**	
11/6/2002	1020	11 Day	Static	Low	SPL1	17	1100	39	490000	290000	
11/6/2002	1030	11 Day	Static	Low	SPL2	18	1200	36	480000	290000	
11/6/2002	1035	11 Day	Static	Low	SPL3	18	1300	36	530000	350000	
11/6/2002	1040	11 Day	Static	Low	SPL4	20	1100	51	520000	350000	
					Ave	**18.25**	**1175**	**41**	**505000**	**320000**	
11/6/2002	955	11 Day	Static	High	SPH1	73	720	38	500000	460000	
11/6/2002	1005	11 Day	Static	High	SPH2	63	770	38	500000	470000	
11/6/2002	1010	11 Day	Static	High	SPH3	60	780	40	540000	510000	
11/6/2002	1015	11 Day	Static	High	SPH4	70	710	39	490000	450000	
					Ave	**66.5**	**745**	**39**	**507500**	**472500**	
11/7/2002	905	12 Day	Turned	Low	MPL1	26	760	45	470000	280000	
11/7/2002	912	12 Day	Turned	Low	MPL2	28	770	44	510000	310000	
11/7/2002	915	12 Day	Turned	Low	MPL3	27	660	45	560000	350000	
11/7/2002	920	12 Day	Turned	Low	MPL4	23	760	39	590000	360000	
					Ave	**26**	**738**	**43**	**532500**	**325000**	
11/7/2002	925	12 Day	Turned	High	MPH1	72	760	42	580000	520000	
11/7/2002	926	12 Day	Turned	High	MPH2	75	560	48	600000	560000	
11/7/2002	923	12 Day	Turned	High	MPH3	74	660	42	540000	500000	
11/7/2002	930	12 Day	Turned	High	MPH4	66	550	46	620000	580000	
					Ave	**71.75**	**633**	**45**	**585000**	**540000**	
2/4/2003	1050	101 Day	Static	Low	SPL1	14	630	40	710000	380000	7
2/4/2003	1055	101 Day	Static	Low	SPL2	22	400	37	730000	390000	7
2/4/2003	1100	101 Day	Static	Low	SPL3	14	630	43	730000	360000	7
2/4/2003	1105	101 Day	Static	Low	SPL4	15	700	40	720000	380000	7
					Ave	**16.25**	**590**	**40**	**722500**	**377500**	
2/4/2003	1110	101 Day	Static	High	SPH1	54	820	68	600000	570000	7
2/4/2003	1113	101 Day	Static	High	SPH2	54	750	65	610000	570000	7
2/4/2003	1116	101 Day	Static	High	SPH3	54	870	64	600000	560000	7
2/4/2003	1120	101 Day	Static	High	SPH4	67	700	65	600000	570000	7
					Ave	**57.25**	**785**	**66**	**602500**	**567500**	
2/4/2003	1137	101 Day	Turned	Low	MPL1	16	1200	63	710000	370000	6
2/4/2003	1140	101 Day	Turned	Low	MPL2	15	1300	54	640000	350000	5
2/4/2003	1143	101 Day	Turned	Low	MPL3	18	1500	56	640000	410000	6
2/4/2003	1146	101 Day	Turned	Low	MPL4	17	1300	58	650000	420000	7
					Ave	**16.5**	**1325**	**58**	**660000**	**387500**	
2/4/2003	1124	101 Day	Turned	High	MPH1	62	800	66	610000	530000	7
2/4/2003	1127	101 Day	Turned	High	MPH2	53	760	67	590000	550000	7
2/4/2003	1130	101 Day	Turned	High	MPH3	53	870	67	620000	580000	7
2/4/2003	1133	101 Day	Turned	High	MPH4	56	960	64	620000	570000	7
					Ave	**56**	**848**	**66**	**610000**	**557500**	
2/5/2003		102 Day	Turned	High	Sample 1-Row4						5
2/5/2003		102 Day	Static	High	Sample 2-Row 3						5
2/5/2003		102 Day	Turned	Low	Sample 3-Row 2						4
2/5/2003		102 Day	Static	Low	Sample 4-Row 1						3

Table 4: Summary of Day 3 Static Pile Flux Data

Position	AGE	S or T	C/N	FID	CO	Tracer	Advect	NH3	TNMHC	Odor	(D/T)/1000ft2,hr-1
			Ratio	lb/1000ft2,hr-1	(ppmv)		CF	lb/1000ft2,hr-1	lb/1000ft2,hr-1	D/T	
Lowest	3 Day	Static	High	**0.00089**	126	184	1.5	**<0.00020**	**0.0196**	NA	NA
Middle	3 Day	Static	High	**0.0051**	103	193	1.9	**<0.00020**	**0.056**	NA	NA
Top	3 Day	Static	High	**0.14**	42	183	4.4	**<0.00020**	**0.280**	NA	NA
Lowest	3 Day	Static	High	**0.00085**	132	184	1.4	**<0.00020**	**0.0170**	NA	NA
Middle	3 Day	Static	High	**0.0024**	123	193	1.6	**<0.00020**	**0.0197**	NA	NA
Top	3 Day	Static	High	**0.15**	39	183	4.7	**<0.00020**	**0.081**	15,000	**33**
Ave				**0.050**			**2.6**	**<0.00020**	**0.079**	**15,000**	**33**
Lowest	3 Day	Static	Low	**0.0029**	136	184	1.4	**<0.00037**	**0.048**	NA	NA
Middle	3 Day	Static	Low	**0.0025**	168	193	1.1	**0.0028**	**0.048**	NA	NA
Top	3 Day	Static	Low	**0.25**	16.8	183	11	**<0.00037**	**0.47**	NA	NA
Top	3 Day	Static	Low	**0.014**	177	184	1.0	**<0.00037**	**0.0286**	3,300	**1.6**
Middle	3 Day	Static	Low	**0.021**	177	193	1.1	**<0.00037**	**0.039**	NA	NA
Lowest	3 Day	Static	Low	**0.011**	14.6	183	13	**<0.00037**	**0.125**	NA	NA
Ave				**0.050**			**4.7**	**0.00078**	**0.126**	**3,300**	**1.6**

Table 5: Summary of Day 4 Turned Pile Flux Data

Position	AGE	S or T	C/N	FID	CO	Tracer	Advect	NH3	TNMHC	Odor	(D/T)/1000ft2,hr-1
			Ratio	lb/1000ft2,hr-1	(ppmv)		CF	lb/1000ft2,hr-1	lb/1000ft2,hr-1	D/T	
Middle	4 Day	Turned	High	**0.0037**	168	184	1.1	**<0.00015**	**0.036**	NA	NA
Lowest	4 Day	Turned	High	**0.00032**	173	183	1.1	**<0.00015**	**0.0212**	NA	NA
Top	4 Day	Turned	High	**0.12**	55.6	193	3.5	**<0.00015**	**0.85**	55,000	**90**
Top	4 Day	Turned	High	**0.0041**	145	193	1.3	**<0.00015**	**0.116**	NA	NA
Lowest	4 Day	Turned	High	**0.10**	57	183	3.2	**<0.00015**	**0.84**	NA	NA
Middle	4 Day	Turned	High	**0.0021**	108	184	1.7	**<0.00015**	**0.052**	NA	NA
Ave				**0.037**			**2.0**	**<0.00015**	**0.320**		**90**
Lowest	4 Day	Turned	Low	**0.0064**	131	183	1.4	**<0.00020**	**0.235**	NA	NA
Middle	4 Day	Turned	Low	**0.022**	130	184	1.4	**<0.00020**	**0.42**	NA	NA
Top	4 Day	Turned	Low	**0.13**	52.6	193	3.7	**<0.00020**	**3.24**	NA	NA
Top	4 Day	Turned	Low	**0.0091**	135	183	1.4	**<0.00020**	**0.071**	3,300	**2**
Middle	4 Day	Turned	Low	**0.22**	30.2	193	6.4	**<0.00020**	**5.4**	NA	NA
Lowest	4 Day	Turned	Low	**0.016**	141	184	1.3	**<0.00020**	**0.313**	NA	NA
Ave				**0.068**			**2.6**	**<0.00020**	**1.61**		**2**

Average Correction Factor for Advective Flow: Static Piles 2.6 (High C:N), Static Piles 4.7 (Low C:N)

Average Correction Factor For Advective Flow: Turned Piles 2.0 (High C:N), Turned Piles 2.6 (Low C:N)

FID (ppmv)(16/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.025)(CF)=FID (mg/m2,min-1)

NH3 (ppmv)(18/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.028)(CF)=NH3(mg/m2,min-1)

Flux Coversion: (mg/m2,min-1)(1 g/1,000mg)(0.0920m2/1ft2)(1 lb/454g)(60 min/1 hr)(1,000ft2) = (mg/m2,min-1)(0.0122) = (lb/1,000 ft2,

Highest value for a replicate pair used rather than average value.

Single value used for 'average' reporting per group of data.

Odor (D/T)(0.005m3/min)/(0.13m2)=(D/T)(0.0385)(CF)=Odor (D/T)/m2,min-1

NH3 MDL- (0.1ug/ml)(25ml)/(0.008m3)= 0.3 mg/m3, (0.3 mg/m3)(18/25 mol wt)= 0.23 ppmv

Average values use MDL if ND reported

Table 6: Summary of Day 11 Static Pile Flux Data

Position	Age	S or T	C/N	FID	CO	Tracer	Advect	NH3	TNMHC	Odor	(D/T)/1000ft2,hr-1
			Ratio	lb/1000ft2,hr-1	(ppmv)		CF	lb/1000ft2,hr-1	lb/1000ft2,hr-1	D/T	
Top	11 Day	Static	High	**0.0014**	166	192	1.2	**<0.00012**	**0.0120**	NA	NA
Top	11 Day	Static	High	**0.011**	58.6	184	3.1	**<0.00012**	**0.0213**	3,900	**5.8**
Middle	11 Day	Static	High	**0.0021**	126	192	1.5	**<0.00012**	**0.0107**	NA	NA
Lowest	11 Day	Static	High	**0.0010**	108	191	1.6	**<0.00012**	**0.0121**	NA	NA
Lowest	11 Day	Static	High	**0.00032**	92	191	2.1	**<0.00012**	**0.0187**	NA	NA
Middle	11 Day	Static	High	**0.00052**	113	192	1.7	**<0.00012**	**0.0134**	NA	NA
Ave				**0.0026**			**1.9**	**<0.00012**	**0.0147**		**5.8**
Top	11 Day	Static	Low	**0.011**	139	192	1.4	**<0.00024**	**0.0130**	MIA	NA
Top	11 Day	Static	Low	**0.028**	44.7	184	4.1	**<0.00024**	**0.046**	NA	NA
Middle	11 Day	Static	Low	**0.0072**	15.5	184	12	**<0.00024**	**0.083**	NA	NA
Lowest	11 Day	Static	Low	**0.0012**	149	192	1.3	**<0.00024**	**0.0062**	NA	NA
Middle	11 Day	Static	Low	**0.012**	150	192	1.3	**<0.00024**	**0.0224**	NA	NA
Lowest	11 Day	Static	Low	**0.054**	101	191	1.9	**<0.00024**	**0.0139**	NA	NA
Ave				**0.019**			**3.6**	**<0.00024**	**0.0307**		**NA**

Table 7: Summary of Day 12 Turned Pile Flux Data

Position	Age	S or T	C/N	FID	CO	Tracer	Advect	NH3	TNMHC	Odor	(D/T)/1000ft2,hr-1
			Ratio	lb/1000ft2,hr-1	(ppmv)		CF	lb/1000ft2,hr-1	lb/1000ft2,hr-1	D/T	
Top	12 Day	Turned	High	**0.029**	36.7	184	5.0	**<0.00012**	**1.51**	12,000	**28**
Top	12 Day	Turned	High	**0.00065**	135	192	1.4	**<0.00012**	**0.120**	NA	NA
Middle	12 Day	Turned	High	**0.00037**	110	192	1.7	**<0.00012**	**0.084**	NA	NA
Lowest	12 Day	Turned	High	**0.0014**	84.8	191	2.3	**<0.00012**	**0.194**	NA	NA
Lowest	12 Day	Turned	High	**0.0020**	88.3	191	2.2	**<0.00012**	**0.0313**	NA	NA
Middle	12 Day	Turned	High	**0.0014**	129	192	1.5	**<0.00012**	**0.0287**	NA	NA
Average				**0.0058**			**2.3**	**<0.00012**	**0.328**		**28**
Top	12 Day	Turned	Low	**0.22**	53.2	184	3.5	**<0.00024**	**0.69**	MIA	NA
Top	12 Day	Turned	Low	**0.053**	128	192	1.5	**<0.00024**	**0.156**	NA	NA
Lowest	12 Day	Turned	Low	**0.032**	126	191	1.5	**<0.00024**	**0.0160**	NA	NA
Middle	12 Day	Turned	Low	**0.0029**	141	192	1.4	**<0.00024**	**0.034**	NA	NA
Middle	12 Day	Turned	Low	**0.0028**	104	192	1.8	**<0.00024**	**0.096**	NA	NA
Lowest	12 Day	Turned	Low	**0.12**	18.4	184	10	**<0.00024**	**0.48**	NA	NA
Average				**0.071**			**3.3**	**<0.00024**	**0.245**		**NA**
QC	NA	NA	NA	NA	NA	NA	2.8	**<0.00022**	**0.049**	NA	NA
QC	NA	NA	NA	NA	NA	NA	2.8	**<0.00022**	**0.056**	NA	NA

Average Correction Factor For Advective Flow: Static Piles 1.9 (High C:N), Static Piles 3.6 (Low C:N), Average 2.8
Average Correction Factor For Advective Flow: Turned Piles 2.3 (High C:N), Turned Piles 3.3 (Low C:N), Average 2.8
FID (ppmv)(16/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.025)(CF)=FID (mg/m2,min-1)
NH3 (ppmv)(18/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.028)(CF)=NH3(mg/m2,min-1)
Flux Coversion: (mg/m2,min-1)(1 g/1,000mg)(0.0920m2/1ft2)(1 lb/454g)(60 min/1 hr)(1,000ft2) = (mg/m2,min-1)(0.0122) = (lb/1,000 ft2,hr-1)
Highest value for a replicate pair used rather than average value.
Single value used for 'average' reporting per group of data.
Odor (D/T)(0.005m3/min)/(0.13m2)=(D/T)(0.0385)(CF)=Odor (D/T)/m2,min-1
NH3 MDL- (0.1ug/ml)(25ml)/(0.008m3)= 0.3 mg/m3, (0.3 mg/m3)(18/25 mol wt)= 0.23 ppmv
Average values use MDL if ND reported

DISCUSSION OF TEST RESULTS

An evaluation of the test results considered the test variables of feedstock control as measured by the C:N ratio and aeration techniques, i.e. static windrows versus windrows mechanically turned with a Scarab. An additional variable that can be evaluated includes compost age since some temporal data, although limited, was taken that can be used to consider compost life cycle effects. The emissions relative to the geometric location, or windrow zone, where the measurement was taken can also be studied. Finally, evaluation of measurement techniques for VOCs can be considered for the inexpensive, hand-held FID method (Flame Ionization Detector) compared to the costly isolation flux chamber method.

Ammonia Emissions

Ammonia (NH_3) emissions were measured on the four test windrows using the isolation flux chamber at 48 locations. Test results include NH_3 emissions for static windrows, turned windrows, high C:N (woody) materials, low C:N (grassy) materials, the first week of composting, the second week of composting, and various windrow zones (lowest, middle, and ridge top of pile). Of the 48 test results for NH_3 emissions, all of the data is less than the detection limit of 0.1 ug/ml or 0.23ppmv with the exception of one sample. The flux data for NH_3 shown in Tables 4 through 7 reflect the non-detection of NH_3 by showing fluxes <0.00037 lb/1,000ft2hr. With 98 percent of the emission data below the detection limit for NH_3, NH_3 is not a concern. Therefore, the subsequent discussion of test results and graphs of the data do not include NH_3. For greenwaste composting operations, NH_3 emissions should not be a regulatory concern.

Effect of Feedstock Control

The effect of feedstock control on emissions was measured by C:N ratio in the windrow materials. In all cases except one, emissions of VOC decreased with increased C:N ratio in the feedstock materials. The average C:N ratio for windrows constructed of predominantly woody materials ranged from 54 to 74 with an overall average of 63 C:N. The average C:N ratio for windrows constructed of predominantly grassy materials ranged from 16 to 26 with an overall average of 20 C:N. Figures 5, 6, 7, and 9 show a decrease in VOC emissions with increased C:N. VOC emissions were decreased by 34 percent to 80 percent. Figure 8 shows a reverse trend of increased VOCs with higher C:N feedstocks. A plot of the overall averages for VOC emissions and C:N feedstocks is shown in Figure 9 which shows a 63 percent decrease in VOCs for high C:N ratio of 67 versus a low C:N ratio of 22. The control of feedstock blends as indicated by C:N ratio appears to be effective in reducing VOC emissions and would be a feasible Best Management Practice (BMP) operating variable for greenwaste compost facility operators to use to control VOC emissions.

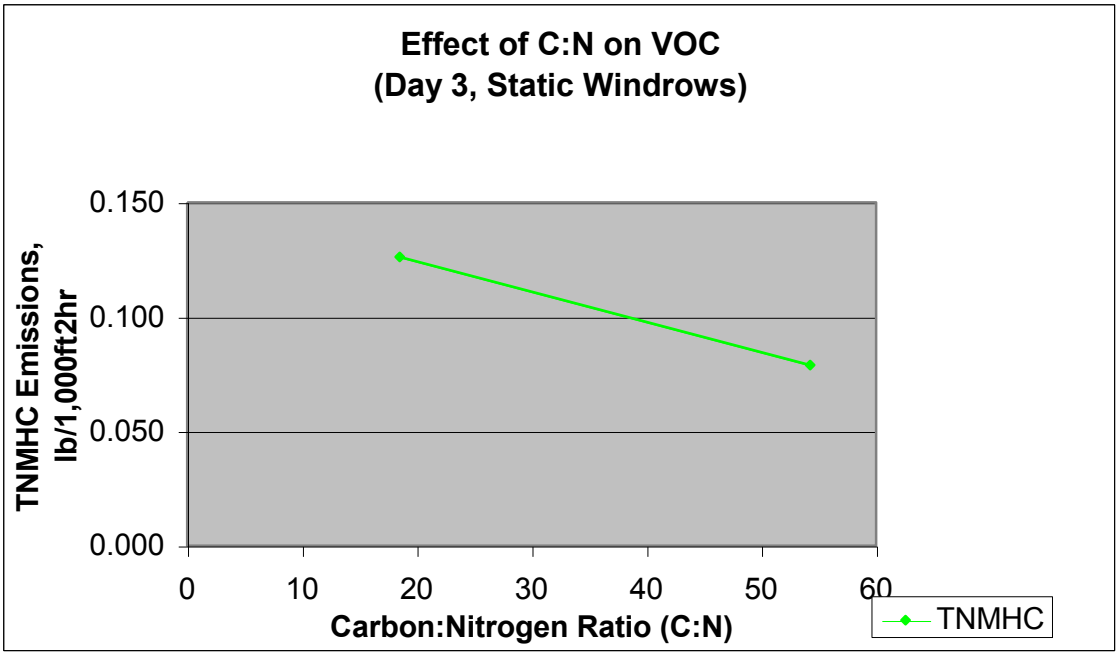


Figure 5: Reduced VOC Emissions for High C:N – Day 3, Static Windrows.

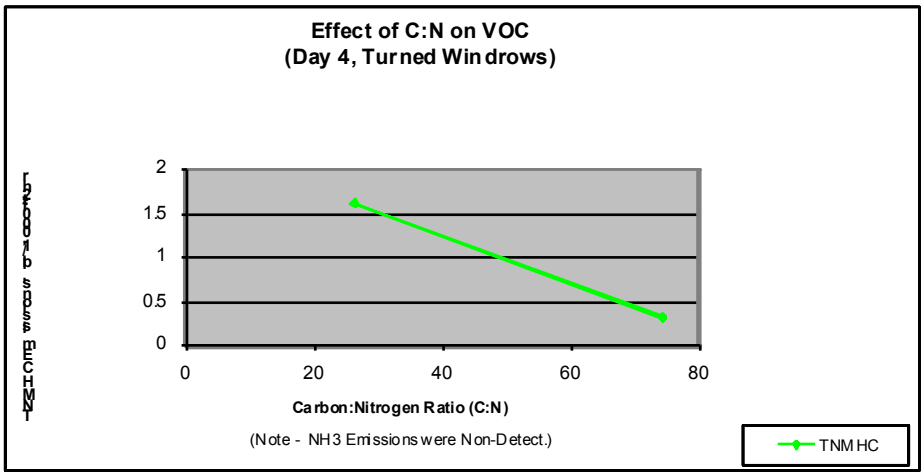


Figure 6: Reduced VOC Emissions for High C:N – Day 4, Turned Windrows.

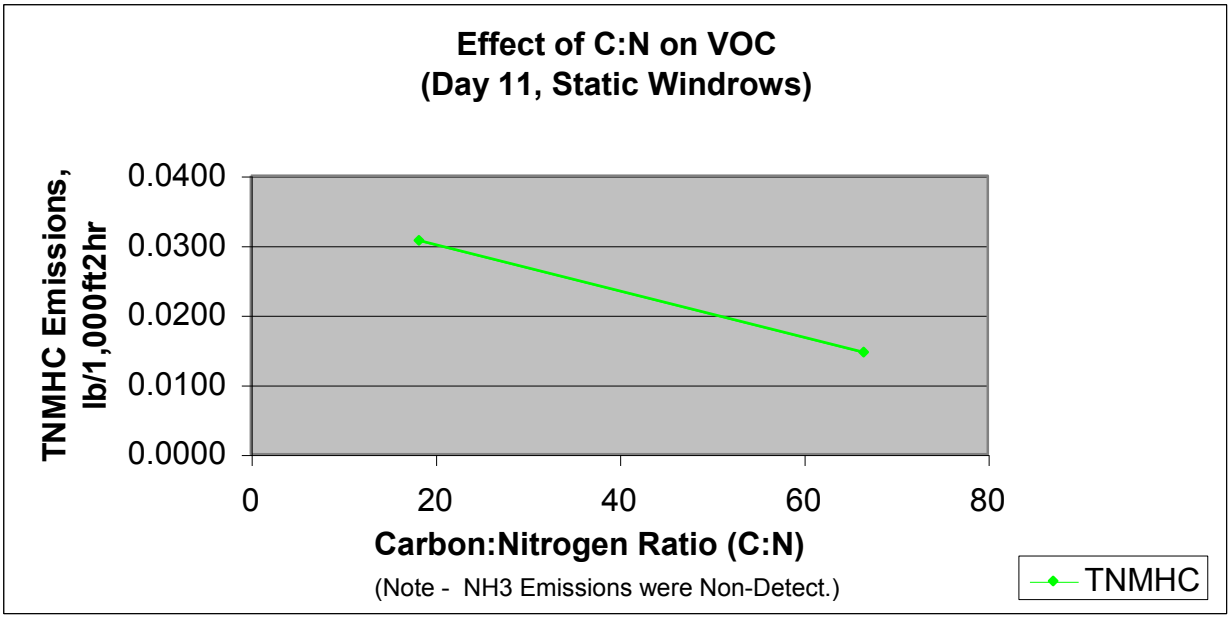


Figure 7: Reduced VOC Emissions for High C:N – Day 11, Static Windrows.

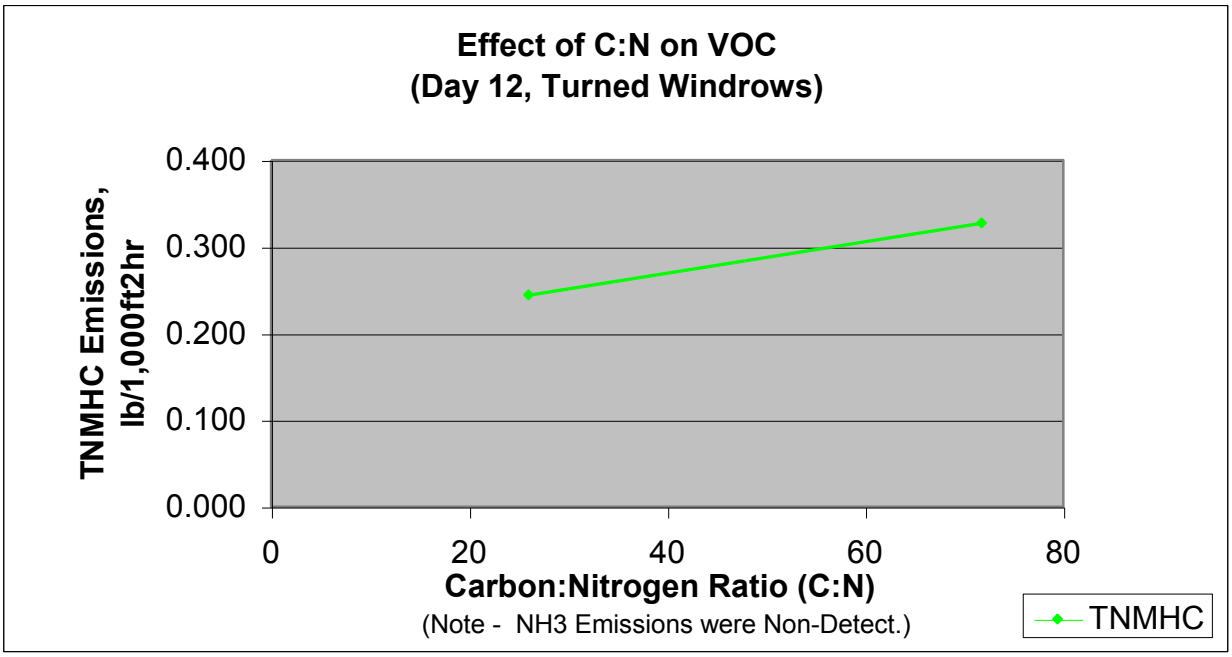


Figure 8: Increased VOC Emissions for High C:N – Day 12, Turned Windrows.

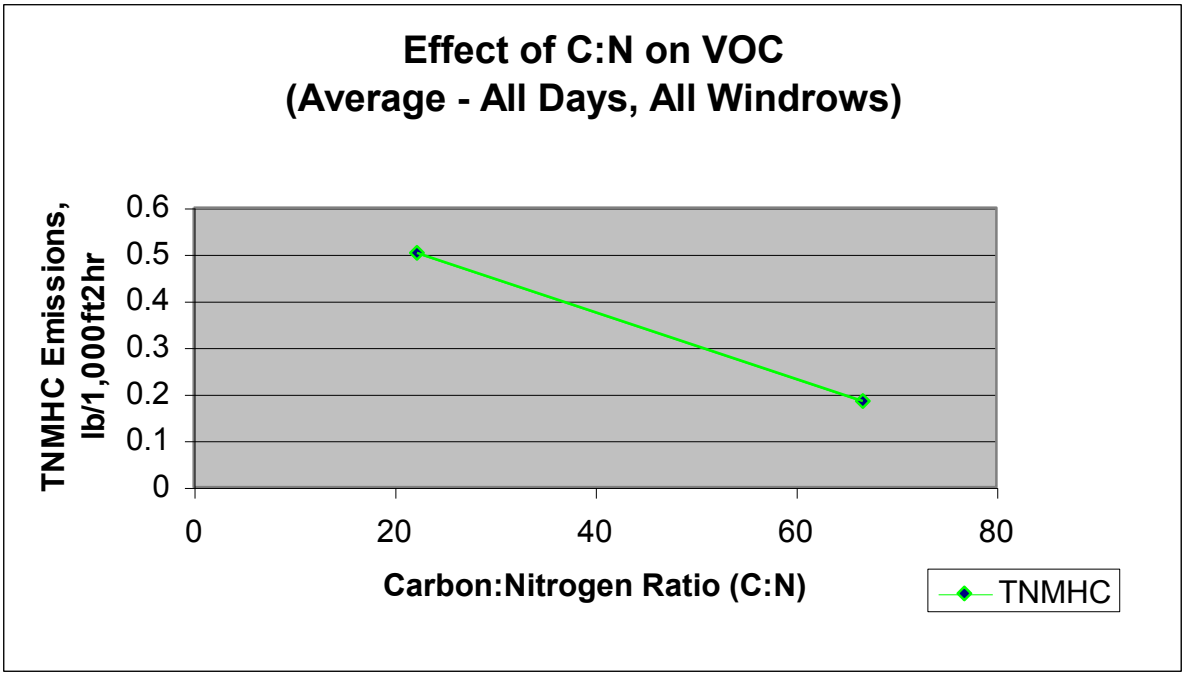


Figure 9: Reduced VOC Emissions for High C:N – Average of All Days, All Windrows.

Effect of Aeration

Emissions were measured on Day 3 and Day 11 for static windrows, i.e. windrows that were not turned but allowed to aerate via natural convection only. Emissions were measured on Day 4 and Day 12 for windrows that were mechanically turned with a Scarab. Figure 10 shows VOC emissions for static windrows compared to turned windrows. The data for Figure 10 shows the average of 12 emission measurements for static windrows on Day 3 of 0.103 lb/1,000ft2hr compared to the average of 12 emission measurements for turned windrows on Day 4 of 0.966 lb/1,000ft2hr. There is an order of magnitude increase in VOC emissions for turned windrows. A similar pattern is observed for data collected on Day 11 and Day 12. Figure 11 shows VOC emissions for static windrows compared to turned windrows for the second week of testing. The data for Figure 11 shows the average of 12 emission measurements for static windrows on Day 11 of 0.022 lb/1,000ft2hr compared to the average of 12 emission measurements for turned windrows on Day 12 of 0.286 lb/1,000ft2hr. Although emissions for both static and turned windrows have decreased by an order of magnitude compared to the previous week, there again is an increase in VOC emissions for turned windrows compared to static windrows at roughly the same age. Without data that defines a full life cycle analysis for emissions over the entire composting cycle, it is difficult to determine based on two points in time if overall emissions are increased, decreased, or the same for static windrows versus turned windrows.

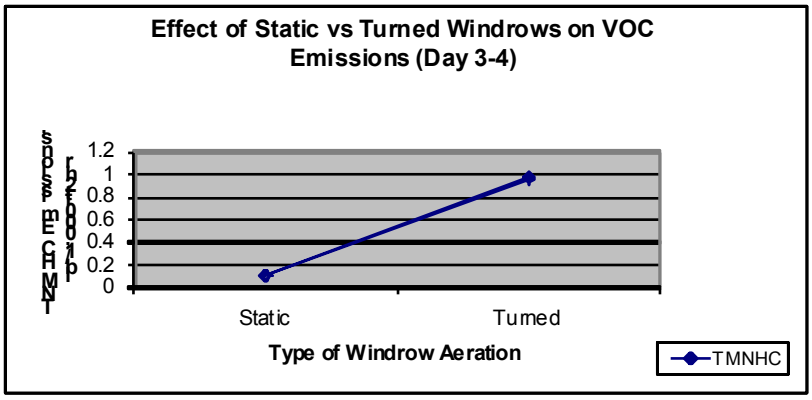


Figure 10: Increased VOC Emissions for Turned Windrow – Day 3 and Day 4.

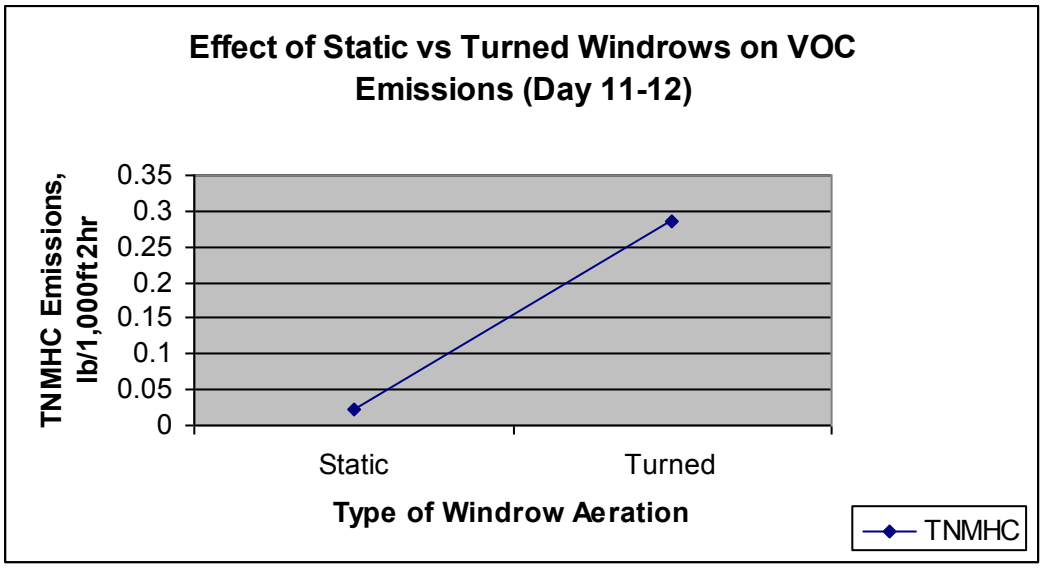


Figure 11: Increased VOC Emissions for Turned Windrow – Day 11 and Day 12.

Effect of Pile Age

The data for two points early in the life cycle during the first two weeks of composting would suggest an increase in VOC emissions for turned windrows as shown in Figure 12. However, this phenomenon may be an indication that aeration increases emissions early in the life cycle by providing a more optimal environment for aerobic reactions, while static windrows result in a steady release of emissions across the entire life cycle of composting. Figure 12 also supports the theory of higher VOC emissions early in the life cycle with emissions tapering off faster for turned windrows. Figure 13 is a conceptual plot that demonstrates this idea. To determine the relative emissions for the two scenarios, the amount of VOCs emitted for each curve must be

summed for the entire life cycle, or in other words, the area under the green curve (turned) must be compared to the area under the red curve (static). As shown in the hypothetical curves, it may be possible to have significantly higher emissions at Day 3/Day 4 for the turned windrows compared to the static windrows; higher emissions at Day 11/Day 12 for the turned windrows but starting to approach the emission levels of the static windrows; and lower overall emissions (area under the curve) for the turned windrows compared to the static windrows. To confirm this would require substantially more life cycle analysis data than was taken for these BMP tests.

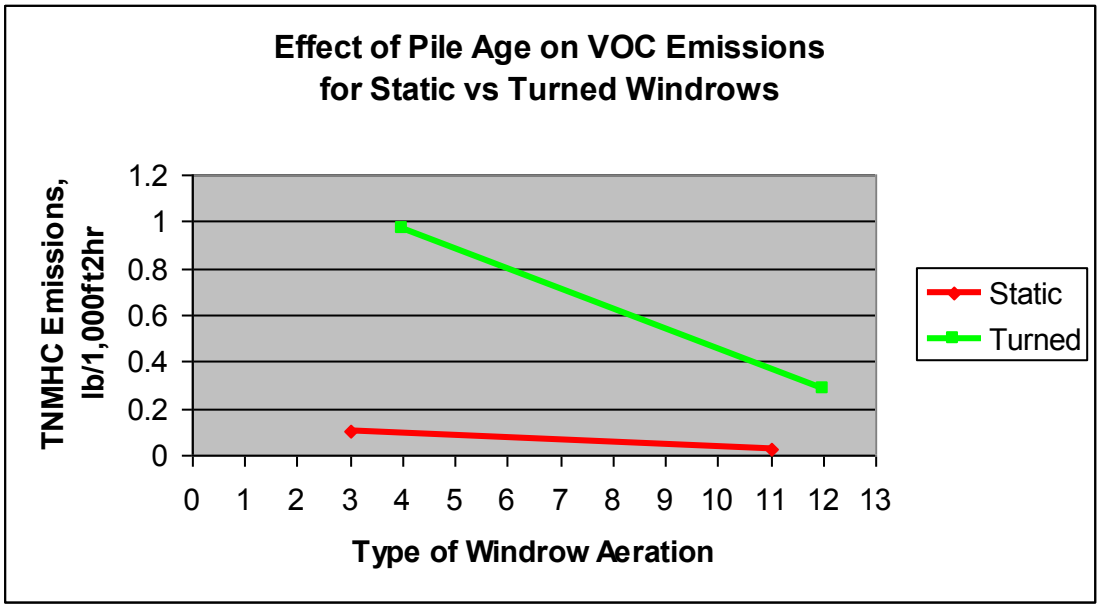


Figure 12: Decreasing VOC Emissions over Time.

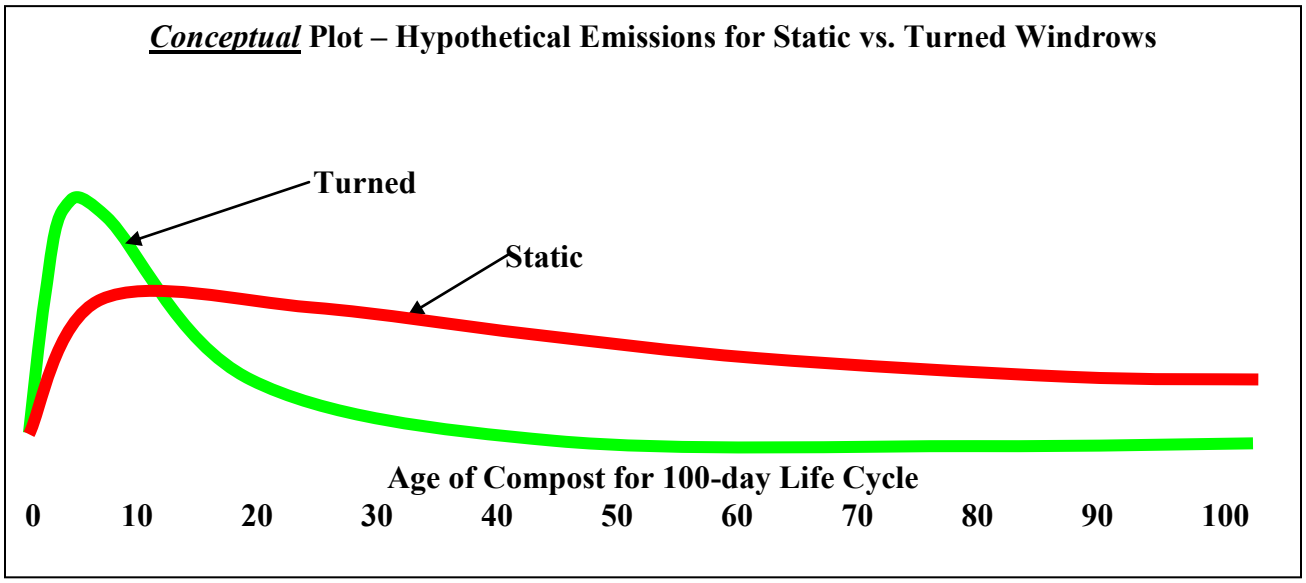


Figure 13: Conceptual Plot of Life Cycle Emissions

The physical characteristics of the compost materials change over time as well. As organic materials compost into finished product, the bulk density increases over time. See Figure 14 for

the effects of pile age on bulk density. Figure 15 shows the how the volatile solids change over time.

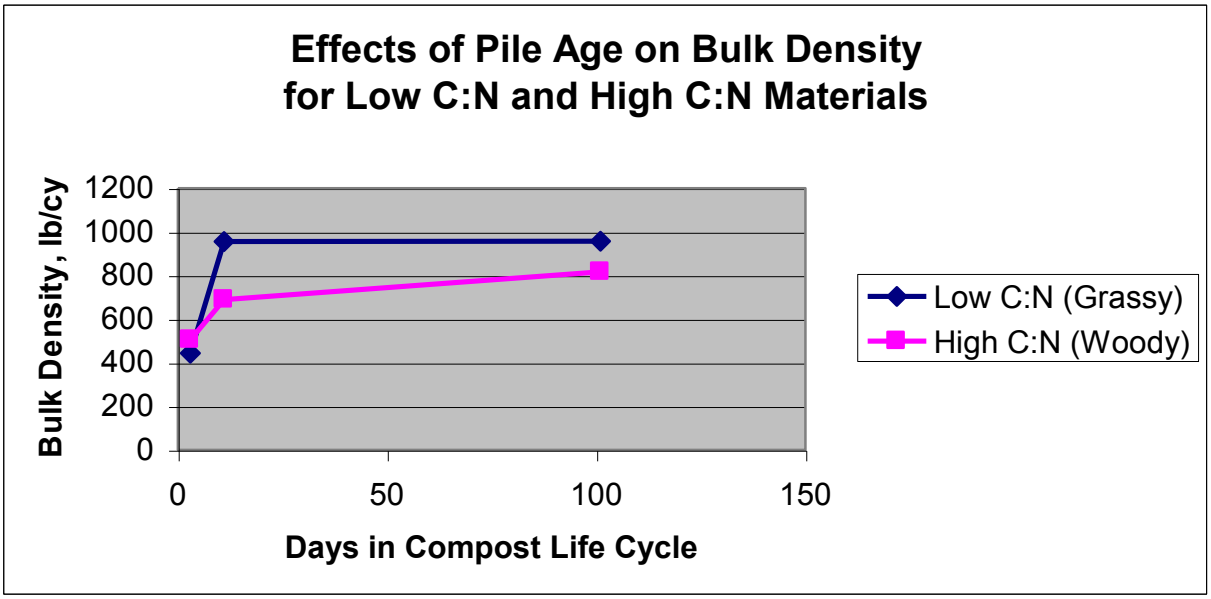


Figure 14: Effects of Pile Age on Bulk Density.

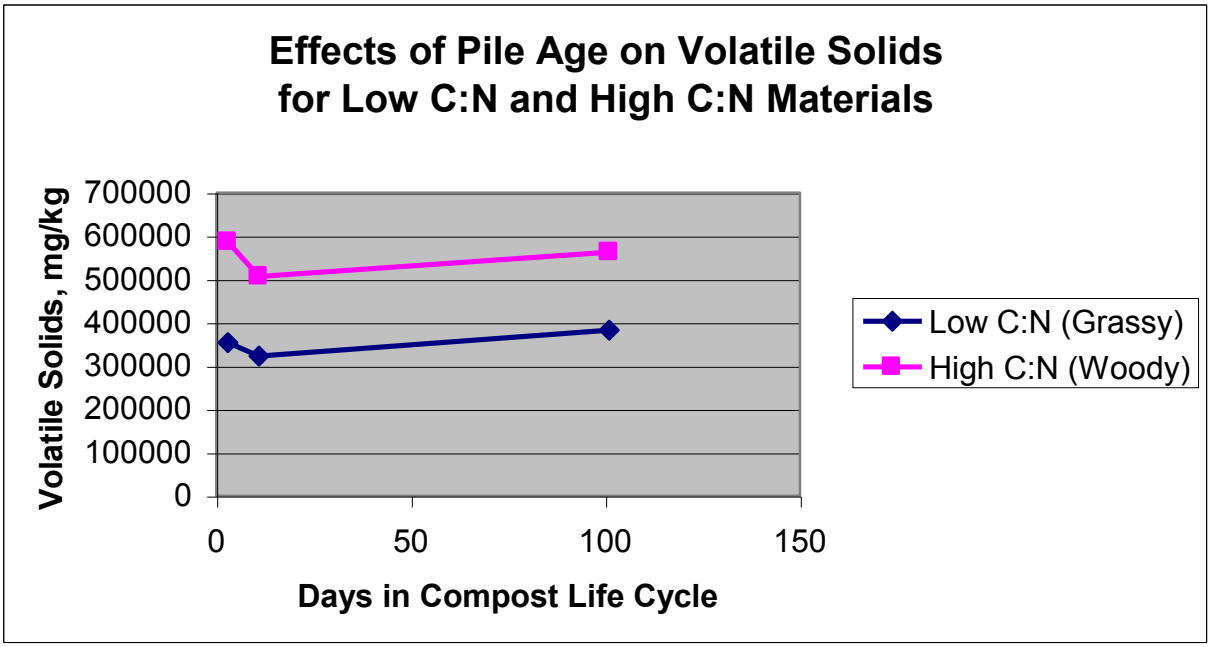


Figure 15: Effects of Pile Age on Volatile Solids.

Product quality tests were also conducted to evaluate the quality of the compost product near the end of the life cycle. Samples were taken on Day 101 and Day 102 and analyzed for a Solvita Maturity Index, an indicator of finished compost. Data for Solvita tests are shown in Table 3. The average Solvita Maturity Index for static windrows was 5.9 while the average Solvita

Maturity Index for turned windrows was 6.6. A Solvita test result in the 5 to 6 range indicates active compost moving into the curing stage. A Solvita test result in the 6 to 7 range indicates curing compost moving into the finished product stage. Since turned windrows have a higher average Solvita that approaches the finished product stage, this would indicate that the static windrows required a longer life cycle to complete the composting process. This is consistent with the conceptual plot of life cycle emissions discussed in Figure 13 but would need to be confirmed with more data. Field observations during product sampling on Day 101 and Day 102 also indicated that the static windrows contained evidence of white strands or filaments characteristic of actinomycetes and fungi that were still actively composting organic materials. The turned windrows did not contain visual evidence of these organisms. See Figure 16 for a photo of the compost product at Day 101 for the static windrows.

Figure 16: White residue, center of photo, indicates active compost for static windrow, Day 101.

Emissions Relative to Windrow Zone

Each windrow was tested at six locations when emission samples were taken with the isolation flux chamber. The test locations included the windrow ridge-top, the sides of the windrow halfway between the ground and the top of the windrow, and the base of the windrow near the ground. The reason for testing for emissions in different windrow zones was to identify directional movement of air intake and emissions outflow. The theory was that for a classic trapezoidal shaped windrow, airflow in would occur at the base and sides of the windrow while emissions out of the windrow would happen on the ridge-top locations. By comparing the

relative VOC fluxes for given windrow zones, directional movement can be determined and venting locations vs. non-venting locations can be identified. Figure 17 and Figure 18 show emissions for the various windrow zones. As shown in these figures, emissions are greatest for the ridge-top locations with the base and side locations of the windrow contributing substantially lower overall emissions. This data confirms the model directional airflow of air intake at the base and sides of the windrow and emissions out of the ridge-top of the windrow. This information can be used to proportionally weight emission factors for trapezoidal windrows when evaluating absolute pounds of emissions from a given windrow or facility. For the data shown in Figure 17 and Figure 18, 22-33 percent of the total emissions for the windrow are coming from the base and sides while 66-76 percent of the total emissions are coming from the windrow ridge-top. Figure 19 shows the total emissions by windrow zone as the average of all of the data for all days and all windrow types. This profile shows more of a 50/50 split of emissions from the tops and sides of the windrows, with 53 percent of the total emissions for the windrow coming from the base and sides while 47 percent of the total emissions are coming from the windrow ridge-top.

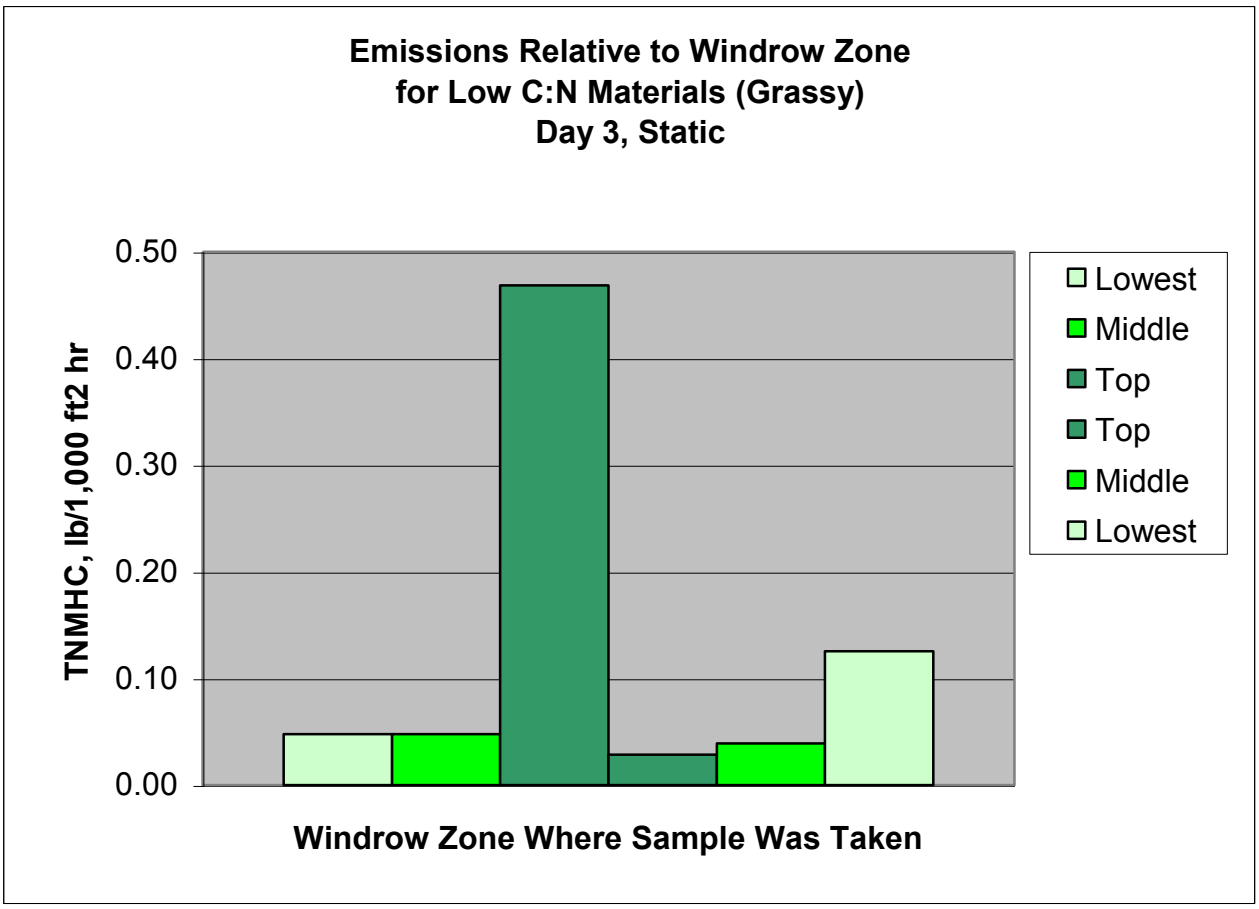


Figure 17: Emissions Relative to Windrow Zone for Low C:N Windrows

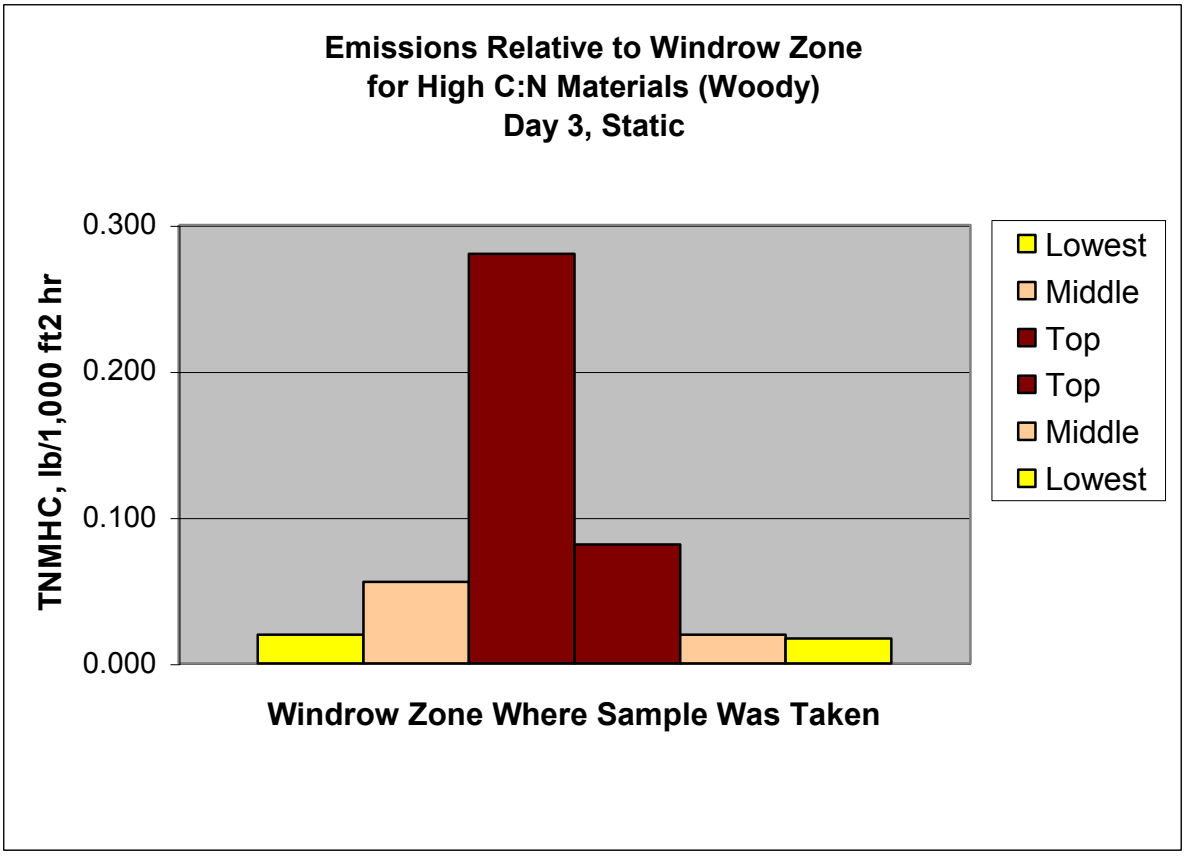


Figure 18: Emissions Relative to Windrow Zone for High C:N Windrows.

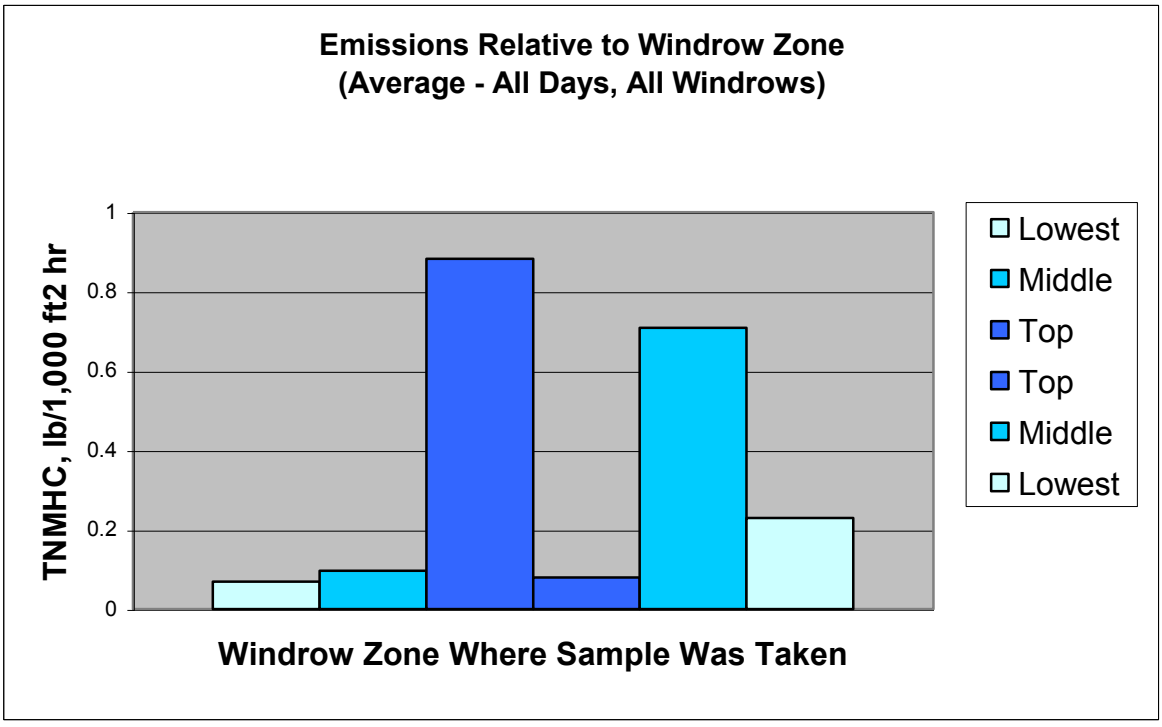


Figure 19: Emissions Relative to Windrow Zone for All Windrows.

FID Correlation to Flux Chamber Measurements

The emission results for FID method measurements can be compared with the emission results for the isolation flux chamber samples analyzed by Method 25.3. The reason for evaluating the correlation between these two methods is to identify an inexpensive method of testing for emissions where a substantial amount of data can be gathered for a wider range of operating variables. The FID method is a hand-held instrument that can be used in the field to obtain a concentration of hydrocarbons emitted from the surface of a windrow. For these tests, an FID reading was taken from the isolation flux chamber. A gas sample was also collected from the flux chamber in a canister and sent to the laboratory for VOC analysis by Method 25.3. The two results, FID and Method 25.3, can be compared to see if there is a consistent relationship between the techniques and determine how well they correlate with each other. Figures 20 through 23 show the correlation between FID and the flux chamber/Method 25.3 for measuring emissions. The data was sorted for feedstock blends and Figure 20 and Figure 21 show the correlation for high C:N and low C:N windrows respectively. The data was re-sorted for aeration technique and Figure 22 and Figure 23 show the correlation for static and turned windrows respectively. As can be seen from these figures, the R^2 factor is between 0.47 and 0.55 meaning that 47-55 percent of the data can be predicted using the exponential or power trend equations shown on the graphs. This indicates that only a moderate correlation can be drawn between the FID and the flux chamber/Method 25.3 results. Without a better correlation between measurement methods, the FID method would not be a good tool to predict the emissions that a flux chamber/Method 25.3 would identify.

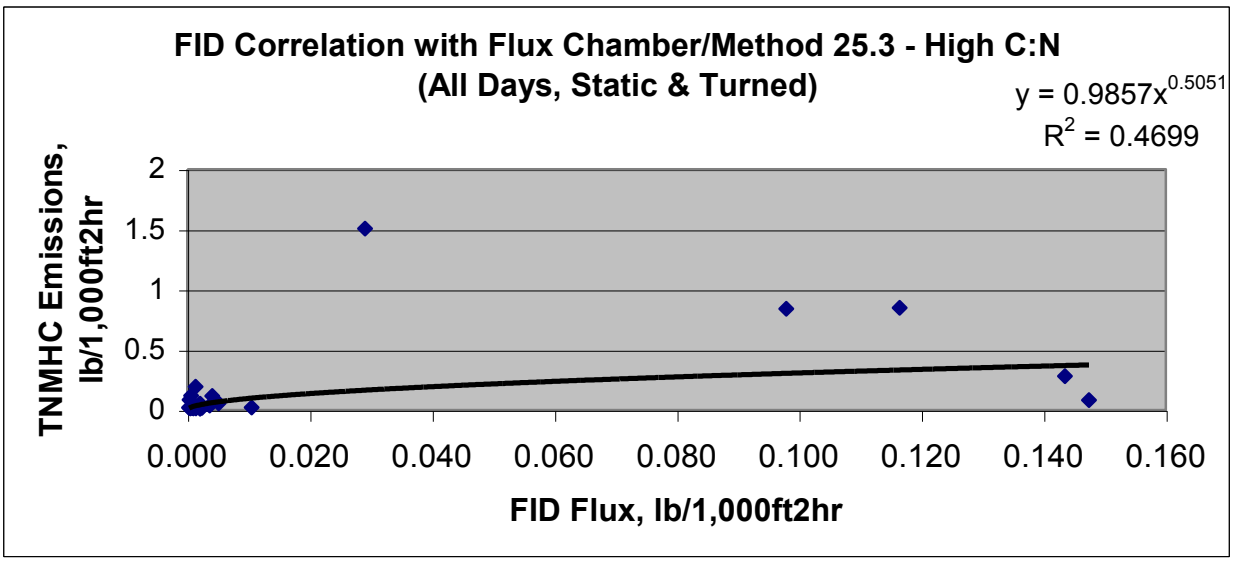


Figure 20: FID Correlation with Flux Chamber/Method 25.3 for High C:N Windrows

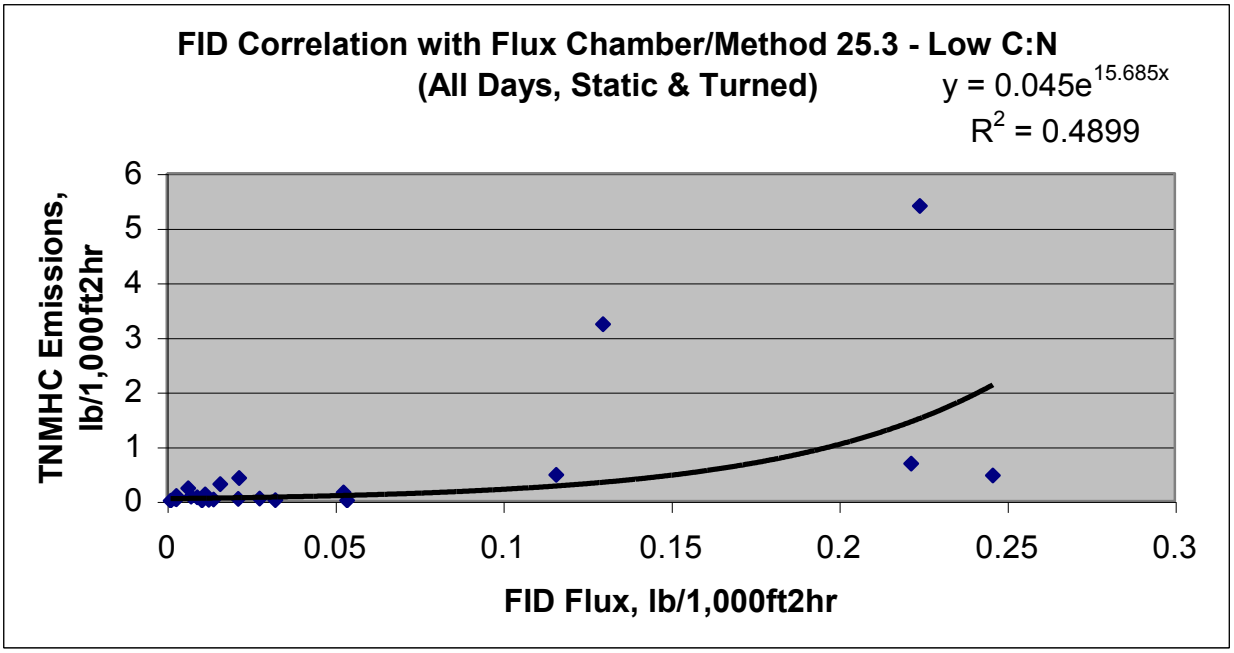


Figure 21: FID Correlation with Flux Chamber/Method 25.3 for Low C:N Windrows

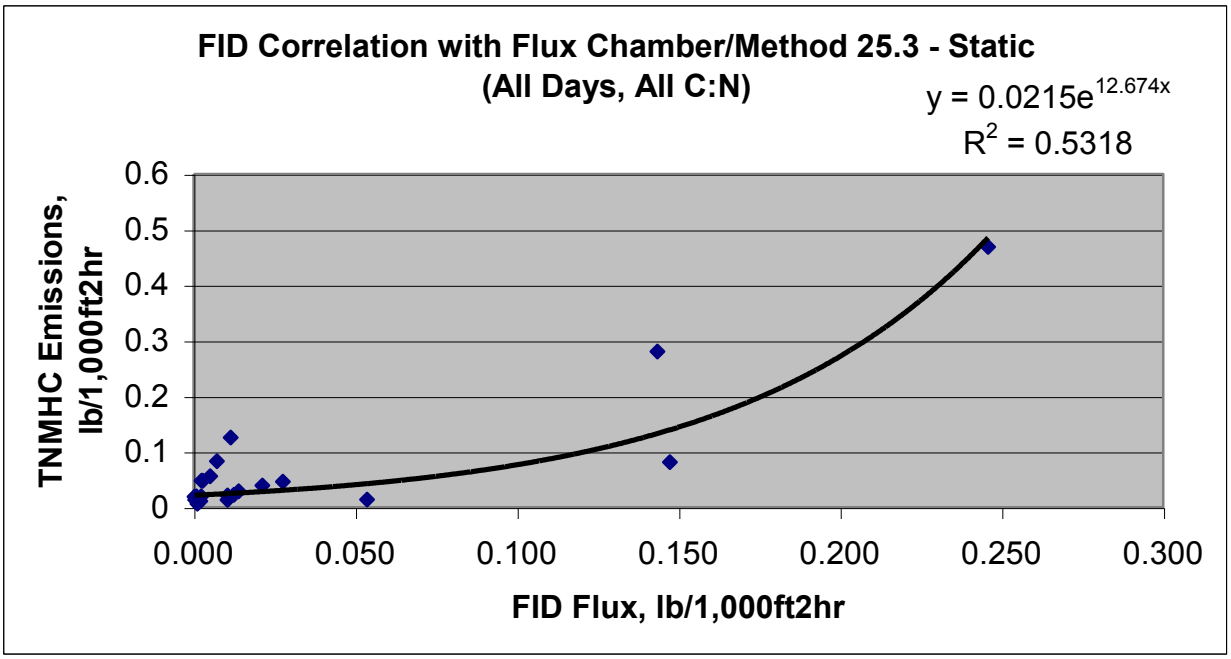


Figure 22: FID Correlation with Flux Chamber/Method 25.3 for Static Windrows.

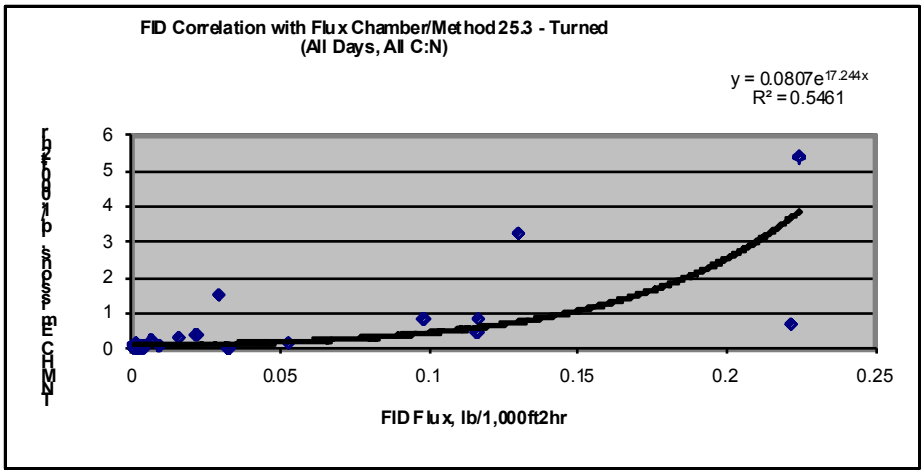


Figure 23: FID Correlation with Flux Chamber/Method 25.3 for Turned Windrows.

Emissions Per Ton of Feed

The VOC emissions for each windrow (for the first two weeks of composting) can be calculated based on the amount of feedstock materials in each of the four test windrows. The amounts of materials were weighed prior to constructing the windrows. Table 8 shows the VOC emissions measured for each windrow as a flux measurement in lb/1,000ft^2, hr^{-1}. The VOC emissions shown are the average of all of the flux measurements taken for each windrow during the first two weeks of the composting process. It should be noted that emission rates during the first two weeks are likely at the highest values and drop off significantly after the initial peak. To determine accurate total emission rates over the entire life cycle of the composting process, additional emission rates that are age-dependent are essential.

Also provided in Table 8 are windrow surface areas, the weight of materials in each windrow, and the calculated emission factors in lbs VOCs per day per ton of feedstock materials. The average VOC emissions were 0.344 lb/1,000ft^2, hr^{-1} for flux measurements and 0.247 lb/day/ton of feed for emission factors.

Table 8: VOC Emissions for Each Windrow				
Row Designation	**VOC Emission Flux* - lb/1000ft2,hr-1**	**Windrow Surface Area-ft2**	**Windrow Amount-lbs**	**Lbs VOC per Day/ Ton of Feed***
Row 1 Emissions (Static, Low C:N) =	0.078	2140	146570	0.055
Row 2 Emissions Turned, Low C:N) =	0.929	2140	147610	0.646
Row 3 Emissions (Static, High C:N) =	0.047	2365	146080	0.036
Row 4 Emissions (Turned, High C:N) =	0.323	2365	147570	0.249
Ave =	**0.344**			**0.247**

*Emission flux and emission rates are based on the VOCs measured during the initial first two weeks of composting. These rates are not representative of the life cycle emission rate which would result in an average emission rate that is significantly lower than the average of the first two weeks of emissions.

CONCLUSIONS

The following conclusions summarize the findings presented in this Technical Summary Report:

- NH_3 emissions are not a concern for greenwaste compost facilities. Emission levels were non-detect in 47 of the 48 test results, equating to 98 percent of the test data below the detection limit for NH_3.

- VOC emissions decreased with an increase in C:N ratio in the windrow materials. Overall averages indicate a 63 percent decrease in VOC emissions for a high C:N ratio of 67 compared to a low C:N ratio of 22.

- Control of feedstock blends, as indicated by C:N ratio, is a feasible BMP operating variable for greenwaste compost facilities to use for minimizing VOC emissions.

- During the early stages of composting, turned windrows emit higher VOC levels than static windrows by an order of magnitude, i.e. 0.965 vs. 0.103 lb/1,000ft^2, hr^{-1} for the first week of composting and 0.287 vs. 0.0227 lb/1,000ft^2, hr^{-1} for the second week of composting.

- VOC emissions peak during the first week of composting and decline by an order of magnitude during the second week of composting, e.g. 0.103 reduces to 0.0227 lb/1,000ft^2, hr^{-1} for static windrows and 0.965 reduces to 0.287 lb/1,000ft^2, hr^{-1} for turned windrows.

- A full life cycle analysis for emissions over the entire composting cycle is needed to determine the overall effects of aeration technique on total VOC emissions. It is difficult to determine if turned versus static windrows emit the more, the same, or less VOCs.

- Turned windrows achieve compost product qualities over a shorter life cycle than static

windrow as evidenced by Solvita Maturity Index results taken at Day 101. The average Solvita test for compost in turned windrows was 6.6, which indicates curing compost moving into the product stage. The average Solvita test for compost in static windrows was 5.9, which indicates active compost moving into the curing stage. Therefore, the static windrows needed more time to complete the composting cycle.

- Emissions vary relative to windrow zone on the surface of the pile. Typically, the emissions are higher for the windrow ridgetop than for the base and sides of the windrow with 50-80 percent of the total emissions coming from the windrow ridgetop.

- Only a moderate correlation can be drawn between the FID and the flux chamber/Method 25.3 techniques of measuring VOC emissions. Although it is significantly less expensive and easier to operate, the FID would not be a good tool to predict the emissions that a flux chamber/Method 25.3 would identify, due to the low prediction accuracy of 47-55 percent.

- The average VOC emissions for the test windrows for the first two weeks of composting were 0.344 lb/1,000ft^2, hr^{-1} for flux measurements and 0.247 lb/day/ton of feed for emission factors.

APPENDIX A

TECHNICAL MEMORANDUM

(Prepared by Dr. C. E. Schmidt)

Reporting of Ammonia and TNMHC Emission Factors from the Surface Flux Chamber Testing Conducted at the Tierra Verde Green Waste Facility Located in Southern California

ENGINEERING EVALUATION

Revised Draft

Prepared For:

Ms. Brenda Smyth
California Integrated Waste Management Board
Organics and Resource Efficiency Branch
1001 I Street
Sacramento, California 95814

Prepared By:

Dr. C.E. Schmidt
Environmental Consultant
19200 Live Oak Road
Red Bluff, California 96080

June 2003

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Field measurements were conducted at the Tierra Verde Industries (TVI) green waste facility located in Irvine, California in the fall of 2002 where test piles of green waste were constructed and maintained as part of an engineering evaluation. For the purposes of this evaluation, TVI hosted the tests, which are not representative of TVI's normal operation. They constructed custom windrows of specific material types and followed prescribed operating procedures for the tests. The tests were designed to simulate extremes in operating conditions, not reflective of TVI's normal operation. Therefore, the emission results from these tests do not represent emissions from TVI.

The project consisted of constructing four test piles of green waste in a fashion similar to standard, full-scale windrow operations. The test variables included feedstock blends of differing carbon to nitrogen ratio content (C/N), static pile operation (aeration by natural convection only), turned pile operation (aeration by mechanical turning), and test pile ageing.

The testing was conducted to measure the air emissions from green waste in support of the SCAQMD Rule 1133, and in support of collecting engineering data that can be used to evaluate

key variables involved in typical windrow operation for green waste composting operations. The goal of the engineering evaluation is to study these key variables and to use this knowledge in developing best management practices for affordably producing acceptable quality compost with the lowest air emissions of sensitive compounds.

The purpose of this document is to report the flux data collected at this facility for the engineering evaluation of: aeration (static pile versus turned pile); feedstock blends (high C/N versus low C/N), and air emissions from static piles as a function of age (Day 3/4 and Day 11/12). This report will also discuss similarities and differences in the data relevant to the test variables, and test methods and potential correction factors that can be used to compare data on the same analytical basis.

The engineering evaluation consisted of constructing and maintaining four windrows of green waste materials that met the flowing descriptions:

Static pile (natural convection only), High C/N Ratio, predominantly woody materials

Static pile (natural convection only), Low C/N Ratio, predominantly grass clippings

Turned pile (mechanically aerated), High C/N Ratio, predominantly woody materials

Turned pile (mechanically aerated), Low C/N Ratio, predominantly grass clippings

Typically, fresh green waste is received at the facility, litter is sorted, and the clean green materials are processed through a grinder. The ground materials are placed in extended windrows, and turned and watered on a schedule dictated by the pile temperature to achieve pathogen reduction requirements. Once active composting is completed, the piles are allowed to remain in place to complete the curing process, so the materials remain in windrows for a total of approximately 120 days. After curing is completed, the windrows are removed, screened, separated into two finished products by particle size, and sold.

The purpose of the testing program was to conduct an engineering evaluation on a full scale, windrow compost operational basis, to determine the effect that key variables, including C/N ratio or composition and aeration, have on air emissions of listed project compounds during the composting phase of the green waste compost operations. Solids sampling and air emission testing were conducted on Day 3/Day 4 of the compost cycle and on Day 11/Day12 in order to analyze the feedstock blends and represent the air emissions from this operation. Compost quality sampling was conducted on Day 103/Day 104 of this operation cycle in order to evaluate product quality. This report documents the air emission testing only.

Source assessment was conducted using the USEPA surface emission isolation flux chamber. The flux chamber was operated as recommended by the USEPA collecting both grab and integrated air samples after equilibrium in the chamber. A tracer gas (carbon monoxide at about 300 ppmv) was added to the sweep air used in the measurement to determine the volumetric flow into the chamber from the green waste static piles. These data were used to generate an advective correction factor for calculating representative air emissions from the test piles.

Ammonia flux was measured by collecting impinger samples (0.1 N sulfuric acid) from the flux chamber for analysis following NMAM 6015. Methane and total non-methane hydrocarbon compounds (TNMHC) were measured by collecting samples from the chamber for analysis by SCAQMD Method 25. 3 for condensable and volatile organic compounds and by USEPA Method TO-15 for volatile and polar hydrocarbon compound speciation at some test locations. In addition, a limited amount of odor sampling using olfactory panel detection was conducted. Quality control testing included blank and replicate tests as well as performance evaluation sample collection/analysis and split-sample collection/analysis by SCAQMD.

Test piles were screened using a variety of techniques including visual observation, surface and subsurface temperature monitoring, surface hydrocarbon screening, and smoke bomb testing. A total of six locations were identified as 'standard' or 'generic' windrow pile test locations. Data from these test locations is intended to represent the air emissions from all three zones of the windrow pile: bottom of pile side material (duplicate test locations), middle of pile or sides of pile (duplicate pile locations), and top of pile (duplicate pile locations).

Engineering Evaluation of Green Waste Compost

Four test piles were constructed on October 26, 2002 consisting of two identical high C/N ratio content windrows and two identical low C/N ratio content windrows. Two piles each were constructed so that the test variable of aeration could be evaluated with same day testing. Test piles were screened and evaluated by the CIWMB and SCAQMD representatives and Dr. CE Schmidt by visual inspection, smoke bomb testing, surface and subsurface temperature screening, and screened for hydrocarbon emissions using a flame ionization detection field instrument sensitive to hydrocarbon compound emissions. Representative test locations were selected that were used to describe air emissions from all windrow test piles involved in the study, including: two random locations (one on each side of the pile) in the bottom one-third of the pile; two locations (one on each side of the pile) in the mid-height of the pile; and two locations along the ridgeline on the top (centerline) of the pile.

Data from all test conditions were represented as average emissions per analyte from all six test locations per windrow, including: two top locations, two side locations (mid-height), and two bottom locations near the toe of the windrow. As such, a simple arithmetic average of the six test pile locations assigns a one-third surface area to each set of spatial data. Although the variability of specific locations may be different from pile to pile, average data can be used as an indicator of pile emissions providing valuable information to the engineering evaluation since the test matrix used for each test pile is identical.

The data from the evaluation can be used as individual data points per pile (Tables 3 through 6), or averaged per pile for comparison purposes (Tables 7a, 7b, and 7c). Averaging data per test pile (per age of pile) is intended to represent pile emissions, since the locations were selected for pile representativeness, and average data are useful because average data allows for a comparison of test parameter (C/N ratio and aeration operation) as a function of age. The following summary statements are provided based on the average data set (Table 7c):

- Static piles have higher advective flow (3.2 factor) as compared to turned piles (2.6 factor) and have decreased advective flow with pile age (Day 3- 2.6 to Day 11- 1.9; Day 3- 4.7 to Day 11- 3.6).

- Turned piles have higher FID flux (0.045 lb/1000ft2,hr-1) as compared to static piles (0.030 lb/1000ft2,hr-1).

- Ammonia flux is low all around (less than detection at about 0.00018 lb/1000ft2,hr-1) with slightly higher flux with fresher (Day 3), low C/N ratio static pile compost (0.00078 lb/1000ft2,hr-1).

- TNMHC flux is much higher in turned piles (0.63 lb/1000ft2,hr-1) than with static piles (0.063 lb/1000ft2,hr-1); highest average flux was found at turned pile (2), low C/N ratio on Day 4 (1.61 lb/1000ft2,hr-1).

- Odor flux is higher in turned piles (40 (odor units/1000ft2,hr-1) than static piles (13 odor units/1000ft2,hr-1); odor is higher with high C/N ratio as compared to low C/N ratio.

- Trap or condensate hydrocarbons dominate 25.3 TNMHC character (>90%): note that sample preparation does not include the purge step like SCAQMD.

- TNMHC flux is generally an order of magnitude lower for aged piles (Day 11/Day 12) as compared to TNMHC flux for new piles (Day 3/Day 4). (Note: In one case, it is the same).

The flux data, used in a relative fashion, can be used to determine which set of operational variables can be used to produce acceptable green waste compost while maintaining acceptable air emissions from compost operations. These data can be used to compare emissions between different types of green waste surfaces and at different stages of production processes or materials used in the green waste mulching operations. Emission profiles for compost production can be developed using these data for site engineering processes. In addition, flux data can be used to estimate TNMHC and ammonia emissions from green waste materials including raw green waste and various grades of mulch on site. Surface flux measured on a given pile of green waste material or mulch can be multiplied by the surface area of the material of that aged/disposition to obtain a material specific TNMHC and ammonia emissions to ambient air.

I. INTRODUCTION

This technical memorandum describes the air emission testing that was conducted as part of an engineering evaluation of key operational parameters in green waste composting. TNMHC and

ammonia emissions were studied in order to assess the effect of C/N ratio and aeration on green waste composting. Testing was conducted on full-scale custom test piles at the Tierra Verde Industries (TVI) facility located in Irvine, California. The test piles are not representative of TVI's normal operation but were constructed specifically for these tests; therefore, the emission results from these tests do not represent emissions from TVI.

Air emission testing was conducted at two different times (Day 3/Day 4 and Day 11/Day 12) during the active phase of the 120-day compost cycle. Testing was conducted by Dr. C.E. Schmidt and Mr. Hoby Rash along with representatives from the facilities, SCAQMD, and the California Integrated Waste Management Board (CIWMB). Site preparation, including providing site operational information and identifying representative materials for testing, was managed by the facilities and the CIWMB.

The objective of these studies was to provide air emissions data (ammonia, TNMHC, odor, and hydrocarbon speciation flux data) representative of air emissions of green waste as part of a process engineering evaluation. Surface flux data can be used, along with information about the engineering process of green waste operations, to assess the air emissions from various engineering scenarios.

This memorandum includes a discussion of the testing methodology, quality control procedures, results expressed as flux (mg/m2,min-1) and emission factors (lb/1,000 ft2,hr-1), discussion of the results, and summary statements.

II. TEST METHODOLOGY

Testing for surface flux was conducted using the USEPA recommended Surface Isolation Flux Chamber (USEPA. Radian Corporation, February 1986). Flux chamber sampling was performed on piles of green waste materials and green waste mulch/compost as found on these sites the day of testing.

The operation of the surface flux chamber is given below:

1) Flux chamber, sweep air, sample collection equipment, and field documents were located on-site.

2) The site information, location information, equipment information, date, and proposed time of testing were documented on the Emissions Measurement Field Data Sheet.

1) The exact test location was selected and the flux chamber placed about 1" into the green waste surface sealing the chamber for open soil surface testing.

4) The sweep air flow rate (ultra high purity air with a carbon monoxide tracer gas additive) was initiated and the rotometer, which stabilizes the flow rate, was set at 5.0 liters per minute. A constant sweep air flow rate was maintained throughout the measurement for each sampling location.

5) Flux chamber data were recorded every residence interval (6 minutes) for five intervals, or 30 minutes.

2) At steady-state (assumed to be greater than 5 residence intervals), the sample collection was performed by interfacing the sample container (tedlar bag or impinger) to the purged, sample line and filling the container with sample gas or collecting the impinger sample.

7) After sample collection (tedlar bag, impinger solution, and evacuated canister if needed), all field data were documented on the data sheet.

8) After sampling, the flux measurement was discontinued by shutting off the sweep air, removing the chamber, and securing the equipment. The chamber was cleaned by dry wipe with a clean paper towel and the sample lines were purged with UHP air.

9) Sampling locations were recorded on the field data sheet. The equipment was then relocated to the next test location and steps 1) through 8) were repeated.

III. QUALITY CONTROL

Control procedures were used to assure that data of sufficient quality resulted from the flux chamber study. The application and frequency of these procedures were developed to meet the program data quality objectives as described in the project work plan (Schmidt, C.E., October, 2002 Engineering Evaluation SOP). Control procedures and QC data collected for all testing activities are reported below.

Field Documentation -- A field notebook containing data forms, including sample chain-of-custody (COC) forms, was maintained for the testing program. Attachment A contains the Emission Measurement Data Sheets.

Chain-of-Custody -- COC forms were not used for field data collection. Field data were recorded on the Chain-of-Custody forms provided in Attachment B.

Ammonia Analysis;SCAQMD 207.1Media Blank – Two media blank samples (0.1 N H2SO4) were analyzed by the laboratory for ammonia. Both media blank samples showed non-detect for ammonia at a method detection limit of 0.1ug/ml solution, which, for this effort, equates to a gas phase method detection limit of approximately <0.21 ppmv . These data indicate acceptable method performance.

Spike Sample Recovery – Eleven samples were spiked and the recovery of spike in sample ranged from 75% to 103% (average 94%). These data are within the QC criteria for the method (70%-to-130%) and are considered acceptable.

Duplicate Spike Sample Recovery – Eleven spike samples were analyzed in duplicate and the range of relative percent difference (RPD) was 0.7 to 7.9 (average 4.2 RPD). These data are within the QC criteria for the method (<25 RPD) and are considered acceptable.

Laboratory Duplicate Analysis – Eleven samples were analyzed in duplicate and all except two were non detect indicating good repeatability but provided no data on laboratory precision. Two of the 11 samples were above detection and the relative percent difference for the duplicate pairs was 0.9 to 1.2 indicating acceptable method performance.

Field System Blank – Four trip blank samples were collected for the ammonia method. The ammonia blanks were non-detect at less than about 0.21 ppmv four samples. These data represent acceptable method performance.

Field Replicate Sample – Four replicate samples were performed for ammonia. All four replicate pairs showed non-detect that indicates good repeatability but offers no data on regarding precision. Acceptable method precision is indicated by the laboratory duplicate analysis and these data indicate acceptable method performance.

Carbon Monoxide Tracer Analysis; SCAQMD Method 25.3

Laboratory Blank – Three laboratory blank samples were analyzed by the laboratory. All three showed showed non-detect for carbon monoxide at the 0.3 ppmv method detection limit. These data indicate acceptable method performance.

Spike Sample Recovery – Three spike samples were analyzed for recovery of carbon monoxide; the recovery of spike (100 ppmv) ranged from 110% to 130% (average 120%). These data are within the QC criteria for the method (70%-to-130%) and are considered acceptable.

Field System Blank/Recovery of Field Tracer – Four trip blank samples were collected for the SCAQMD 25.3 method. The blanks included the carbon monoxide tracer in the flux chamber sweep air and represent field recovery of carbon monoxide from a primary standard. These data as given below were used to represent the advective flow in the chamber. The average recovery from these blank samples were used to scale the carbon monoxide reported in the field samples and used to estimate an advective flow into the chamber (by dilution of field tracer). The average recovery for carbon monoxide was 62%.

C-BLK-001	Tracer at 296 ppmv	Recovery at 194 ppmv	Percent Recovery 66
C-BLK-002	Tracer at 195 ppmv	Recovery at 211 ppmv	Percent Recovery 72
C-BLK-004	Tracer at 308 ppmv	Recovery at 162 ppmv	Percent Recovery 53
C-BLK-005	Tracer at 309 ppmv	Recovery at 172 ppmv	Percent Recovery 56

(Note- there was no C-BLK-003 sample; non-consecutive field numbers)

Field Replicate Sample – Four replicate field samples were analyzed for carbon monoxide All four replicate pairs showed acceptable RPD: 2.4, 2.6, 10, 11, average RPD 6.5. These data indicate acceptable method performance.

TOC/NMHC Analysis

Laboratory Method Blank - Four method blank samples were conducted for TOC and NMOC and TOC and NMOC were not detected above the method detection limit of 0.3 ppmv. These data indicate acceptable method performance.

Duplicate Spike Sample Recovery – Four low concentration spike samples were analyzed in duplicate. The recovery for TOC ranged from 93% to 107% (average 96%) and the range of RPD was 2.6 to 5.8 (average RPD of 4.0). The recovery for NMOC ranged from 94% to 100% (average 98%) and the range of RPD was 2.5 to 11 (average RPD of 5.9). These data are within the QC criteria for the method (<30 RPD) and are considered acceptable.

Laboratory Method Duplicate Samples- A total of four samples were analyzed in duplicate in the laboratory. All duplicates were reported within the precision criteria of 30 RPD. The TOC RPD ranged from 4.1 to 12 (average RPD 6.6) and the NMOC RPD was non-detect at 0.3 ppmv. These data indicate acceptable method performance.

Matrix Spike Samples – Four method spike samples were analyzed for TOC and NMOC in replicate. The recovery for TOC ranged from 102% to 119% (average 107%) and the range of RPD was 1.2 to 8.4 (average RPD of 4.3). The recovery for NMOC ranged from 92% to 97% (average 95%) and the range of RPD was 0.9 to 4.1 (average RPD of 2.7). These data are within the QC criteria and are considered acceptable.

Field System Blank – Four media blank samples were analyzed for TNMHC, tank (VOCs) and trap (condensable hydrocarbons). Field blanks samples were collected by filling both the tank and the trap with pure media. Ultra high purity air was added directly into clean, evacuated canisters. Hydrocarbon free water (impinger solution) placed in clean impingers and then transferred into clean VOA vials. The data for the blanks samples, along with blank data collected during a separate field program (identical field blank collection and analysis) during the same time period, is provided below (note- see page 11 for explanation on performance evaluation samples and resulting correction factors for tank/trap/THMHC values):

CIWMB Blank Data

	Tank (ppmv)	***Trap (ppmv)***	***TNMHC (ppmv)***
C/T-BLK-001	14.1	45.0	48.7
C/T-BLK-002	4.1	32.0	27.3
T/C-BLK-4	20.0	46.8	57.2
B-C-BLK-4/5	27.1	45.3	65.0

City of Los Angeles Data (same time period, same lab- data provided for comparison only)

L/G-119	**<0.3**	**2.4**	**2.4**
L/G-214	<0.3	4.7	4.7

The CIWMB tank or canister blank data ranged from 4.1 to 27.1 ppmv greatly exceeding the method detection limit and laboratory blank samples at 0.3 ppmv. Likewise, the trap blank data ranged from 32 to 46.8 ppmv also greatly exceeding the method detection limit and laboratory blank samples at 0.3 ppmv. These blank levels exceeded a high percentage of field samples, exceed method acceptability, and also exceed field or media blank data collected in the identical fashion (hydrocarbon free water reagent introduced directly into the impinger container and then sample bottle, and hydrocarbon free air directly into the canister) from a similar testing program conducted concurrently for the City of Los Angeles. The City of Los Angeles field blank data were marginally acceptable, however these blank data are not. Given that no field equipment (i.e., flux chamber or sample collection lines) came in contact with the blank samples other than transfer to and from a clean 25.3 impinger, there is no known source for these high blank levels other than sample miss-identification and/or laboratory error. Field data below the highest of the tank (27.1 ppmv) and trap (46.8 ppmv) blank levels can be qualified as necessary. These data indicate a field and analytical method blank limitation.

Field Replicate Sample – Four replicate samples were performed for Method 25.3. Tank levels were below detection for 7 of the 8 samples and replicates except one replicate showed 11.5

ppmv in the tank. There was no detection in the sample and no data on precision was available. These data for this sample/replicate pair show poor repeatability, however. TNMHC was detected in all 8 of the sample/replicate pairs for the trap component of the methods and 3 of the 4 sample/replicate pairs were within the QC criteria (RPD of 50) as follows: RPD 0.63, RPD 3.0, RPD of 6.7, and RPD or 52; average RPD of 16. These data indicate acceptable method performance.

Odor Analysis

Laboratory Method Blank - One method blank sample was conducted by filling a clean odor bag with ultra high purity air. The odor level of the blank was 15 D/T (dilution-to-threshold concentration). This level of blank is common for tedlar bags and these data indicate acceptable method performance.

Field Replicate Sample- One odor sample was collected and analyzed in replicate. The sample/replicate had an RPD of 9.0, within the precision criteria of 30 RPD. These data indicate acceptable method performance.

USEPA Method TO-15 Hydrocarbon Speciation Analysis

A limited amount of hydrocarbon speciation analysis was performed (four samples) and, as such, no additional laboratory or field QC data were collected. The analysis was performed according to method procedures.

V. RESULTS AND DISCUSSIONS

A summary of sample collection data for the Part 1 engineering evaluation testing are presented in Table 1 for the testing of green waste compost on Day3/Day4 (10/29/02 and 10/30/02) and Table 2 for the testing of compost on Day11/Day 12 (11/06/02 and 11/07/02). Sample collection information and raw field data are provided and used to calculate flux as reported on subsequent data tables. Flux data, calculated from field and laboratory data, are presented by waste pile and age in Table 3 through Table 6. Table 3 reports the summary of flux data for all species of interest for Day 3 aged green waste (high and low C/N ratio). Table 4 reports the summary of flux data for all species of interest for Day 4 green waste compost (high and low C/N). Table 5 reports the summary of flux data for all species of interest for Day 11 aged green waste (high and low C/N ratio). And Table 6 reports the summary of flux data for all species of interest for Day 12 green waste compost (high and low C/N). All species of interest are reported in concentration units (mg/m3 or D/T) and flux units (mg/m2,min-1 and (D/T)/m2,min-1; lb/1,000ft2,hr-1 and (D/T)/1,000ft2,hr-1). The sample specific advective correction factor derived from the recovery of carbon monoxide tracer was used to calculate flux for all samples. These data can then be compared to data produced by SCAQMD or CIWMB during other investigations.

All data have been reduced to average data sets per green waste type (high or low C/N ratio, aerated or not) and age. These data are presented in Tables 7a, 7b, and 7c. Table 7a represents the average data for static piles and turned static piles for Day 3 and Day 4 aged green waste. Table 7b represents the average data for static piles and turned static piles for Day 11 and Day 12 aged green waste. This data presentation allows for a simple comparison of all classes of aged, high and low C/N green waste in static and turned piles. Finally, all reduced data are presented in Table 7c showing all data averaged by type and age and by compost aeration (static or turned piles), and the average of flux (lb/1000ft2,hr-1) for all piles. This simple summary table can be used to compare the effect of age, green waste composition, and aeration (operation of turning) for all test flux data. Also note that exempt compounds have not been subtracted from the emissions results. In order to calculate emissions of concern to the SCAQMD, exempt VOCs should be identified and subtracted from the total measured emissions. A list of exempt compounds is included in Attachment A.

A limited data set for hydrocarbon speciation of selected samples is provided in Table 8. A total of 8 sample locations were selected from each test pile (4 total) for both testing events in order to obtain a cross-section of data that may be useful for understanding and perhaps properly partitioning hydrocarbon emissions from green waste composting operations. As with hydrocarbon speciation data collected from other CIWMB projects, the hydrocarbon mass (TNMHC) appears to be dominated by polar compounds, specifically methanol, acetone, isopropyl alcohol, 2-butanone, and 4-methyl-2-pentanone.

Finally, headspace gas samples were collected by CIWMB staff from the various piles on all test days and analyzed by CIWMB and the SCAQMD for methane, oxygen, and carbon dioxide. These data were intended to assist in answering questions regarding biological activity in the piles and are provided in Tables 9a and 9b.

Surface flux data for a surface area source are calculated using measured target compound concentrations and flux chamber operating parameter data (sweep air flow rate of 5.0 liters per minute [L/min], surface area of 0.13 square meters [m^2]). The site emissions can be calculated by multiplying the flux by the surface area of the source. The flux is calculated from the sweep air flow rate Q (cubic meters per minute [m^3/min]), the species concentration Yi (micrograms per cubic meter [mg/m^3)], and exposure to the chamber surface area A (square meters [m^2]), as follows:

$$Fi = (Q)\ (Yi) / (A)$$

Emission rate from a given green waste surface can be calculated by multiplying unit flux data per compound by surface area. Emission profiles can be generated by knowing the engineering considerations of the green waste compost production and the target compound flux.

All flux data has been corrected for advective flow as determined by recovery of an inert tracer gas carbon monoxide that was added to the ultra high purity sweep air at nominally 300 ppmv. A small amount of carbon monoxide is generated from static pile composting but this amount is far below concern and near the method detection limit. Carbon monoxide was selected as a tracer gas because it can be detected in the analysis of hydrocarbons by Method 25.3 at no additional cost. Carbon monoxide levels recovered from the field samples were adjusted based on the recovery of carbon monoxide as reported in four blank samples. The average recovery of the field tracer, despite near 100 percent recovery of carbon monoxide in laboratory QC, was 62 percent. This recovery was applied to the tracer level and used with the reported carbon monoxide levels in the field samples to provide for a sample specific (location/pile/compost type-condition-age) advective flow correction in the flux chamber. As such, all data corrected for advective flow, represent the most accurate flux of study compounds possible. It is interesting to note that the field instrument for carbon monoxide, calibrated and used in the same calculation without sample storage produced very similar advective correction factor data as compared to the correction factors generated by using the off-site laboratory data for carbon monoxide.

In an attempt to understand the assessment process (i.e., flux chambers used to measure emissions from compost piles using various analytical methods) three additional data sets were also collected: split samples by the SCAQMD; performance evaluation sample using a SCAQMD laboratory standard; and flux chamber tubing rinsate samples. Split samples were collected by the SCAQMD for sample SP3-2-C/T-002 in replicate (SCAQMD #128 and #129). The sample results are as follows:

	Tank (ppmvC)	***Trap (ppmvC)***	***TNMHC (ppmvC)***
SP3-2-C/T-002	<0.3	141	97.6

(note- differences in analytical procedure between labs can account for differenced is apportionment in hydrocarbon between tank and trap)

SCAQMD #128	68	16	84

SCAQMD #129	72	28	101

The SCAQMD provided a standard calibration gas (bottled gas mixture) in the field and a blind performance sample was collected and analyzed by Method 25.3. The results are provided below.

	Tank (ppmvC)	***Trap (ppmvC)***	***TNMHC (ppmvC)***
SP6-1-C/T-001	342	142	483
SCAQMD Standard	1004	747	1,751

The recovery of PE sample in the trap was 142 ppmvC of 747 ppmvC or 19% recovery, 342 ppmvC of 1004 ppmvC in the tank or 34% recovery, and 482 ppmvC of 1751 ppmvC TNMHC or 28% recovery. All raw data were adjusted using the recovery of the PE sample results using the following correction factors: trap- 5.2, tank- 2.9, and total- 3.6. These parameters were corrected individually and reported in this document as such, despite the fact that the corrected tank and trap values do not add-up to the TNMHC value. This approach allows for the most accurate accounting of the tank, trap, and total values possible

Finally, one aspect of flux chamber testing was studied that was deviant from the SCAQMD protocol. The standard SCAQMD protocol for field sample collection using Method 25.3, a stationary stack testing method, calls for using a short sample collection line from the stack center to the tank/trap train located at the stack outside wall. As such with a short sample line (12" or less), the method calls for a rinse of the sample line from the inlet to the trap after sample collection is complete including the rinsate in the condensate trap collection. However, with porous pile testing, especially on the pile top or high on the sides of the pile where activity around the flux chamber may cause a disturbance to the flux event, a sample line of approximately 12' was used to avoid placing testing equipment immediately next to the flux chamber and disturbing the pile test location. Sample lines were back-flushed with pure air between sample points but not rinsed into the condensate trap per test. On three occasions, the sample line was rinsed and the results showed high levels of THMHC in the rinsate collections:

	Trap (ppmvC)	***Comment***
SP-3-2-C/T-002 (SCAQMD sample)	NA	SCAQMD Lab
TP2-1-L (location TP2-2-T-020)	19.1	Low level emissions
TP2-3-L (location TP2-3-T-021)	149	High level emissions

These data indicate significant sample loss in the long sample line. However, the amount of the actual accumulation and significance of it is not known since the line, even back-flushed with pure air between sample points, may have had deposits from the prior sample locations. The inside of the chamber is completely saturated with condensate during the equilibration time period and sample collection and the chamber contents drops greatly in temperature (surface temperatures over 110 Deg F and inside air temperatures around 90 Deg F) as compared to ambient temperatures around 70 Deg F. As such, condensation in the sample line is relatively minor compared to condensation in the flux chamber and, of course, in the cold finger trap at 32

Deg F. These data suggest that there is sample loss, specifically condensate THMHC, in the long sample lines and that sample line rinsing and collection should be considered for future testing events. It should be noted that this potential sample loss issue in sampling lines has been evaluated at prior testing events by CIWMB. Split samples collected by SCAQMD directly from the flux chamber (very short sample line) and samples collected by CIWMB in 12' sample lines without sample line rinsing, and these data compared very well indicating no significant difference in sample collection protocol. The difference is that the long sample line avoids disturbing the compost pile around the flux chamber, which may affect the flux measurement.

V. SUMMARY

The following is a summary of activities and results associated with the project objectives:

- Static piles have higher advective flow (3.2 factor) as compared to turned piles (2.6 factor) as expected, and have decreased advective flow with pile age (Day 3- 2.6 to Day 11- 1.9; Day 3- 4.7 to Day 11- 3.6).

- Turned piles have higher FID flux (0.045 lb/1000ft2,hr-1) as compared to static piles (0.030 lb/1000ft2,hr-1).

- Ammonia flux is low all around (less than detection at about 0.0.00020 lb/1000ft2,hr-1) with slightly higher flux with fresher (Day 3), low C/N ratio static pile compost (0.00078 lb/1000ft2,hr-1).

- TNMHC flux is much higher in turned piles (0.63 lb/1000ft2,hr-1) than with static piles (0.063 lb/1000ft2,hr-1); highest average flux was found at turned pile (2), low C/N ratio on Day 4 (1.61 lb/1000ft2,hr-1).

- Odor flux is higher in turned piles (40 (odor units/1000ft2,hr-1) than static piles (13 odor units/1000ft2,hr-1); odor is higher with high C/N ratio as compared to low C/N ratio.

- Trap or condensate hydrocarbons dominate 25.3 TNMHC character (>90%): note that sample preparation does not include the purge step like SCAQMD.

- TNMHC flux is lower (or the same) for aged piles (Day 11/Day 12) as compared to TNMHC flux for new piles (Day 3/Day 4).

The flux data, used in a relative fashion, can be used to determine which set of operational variables can be used to produce acceptable green waste compost while maintaining acceptable air emissions from compost operations. These data can be used to compare emissions between different types of green waste surfaces and at different stages of production processes or materials used in the green waste mulching operations. Emission profiles for compost production can be developed using these data for site engineering processes. In addition, flux data can be used to estimate TNMHC and ammonia emissions from green waste materials including raw green waste and various grades of mulch on site. Surface flux measured on a given pile of green waste material or mulch can be multiplied by the surface area of the material of that aged/disposition to obtain a material specific TNMHC and ammonia emissions to ambient air.

REFERENCES

US EPA. 1986. "Measurement of Gaseous Emission Rates From Land Surfaces Using an Emission Isolation Flux Chamber, Users Guide." EPA Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, EPA Contract No. 68-02-3889, Work Assignment No. 18, Radian Corporation, February 1986. NTIS # PB 86-223161.

Schmidt, C.E. Source Test Protocol: CIWMB Green Waste Compost Facility BMP Testing at the Tierra Verde Site Using the USEPA Flux Chamber for Ammonia and VOC Emissions, October, 2002.

ATTACHMENT A

EXEMPT COMPOUNDS are any of the following compounds:

(A) Group I

1,1,1,2,3,4,4,5,5,5-decafluoropentane (HFC-43-10mee)

1,3-dichloro-1,1,2,2,3-pentafluoropropane (HCFC 225cb)

3,3-dichloro-1,1,1,2,2-pentafluoropropane (HCFC 225ca)

acetone

ethane

chlorodifluoromethane (HCFC-22)

trifluoromethane (HFC-23)

2,2-dichloro-1,1,1-trifluoroethane (HCFC-123)

2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124)

pentafluoroethane (HFC-125)

1,1,2,2-tetrafluoroethane (HFC-134)

1,1,1,2-tetrafluoroethane (HFC-134a)

1,1-dichloro-1-fluoroethane (HCFC-141b)

1-chloro-1,1-difluoroethane (HCFC-142b)

1,1,1-trifluoroethane (HFC-143a)

1,1-difluoroethane (HFC-152a)

cyclic, branched, or linear, completely fluorinated alkanes

cyclic, branched, or linear, completely fluorinated ethers with no unsaturations

cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations

sulfur-containing perfluorocarbons with no unsaturations and with sulfur bonds only to carbon and fluorine.

difluoromethane (HFC-32)

1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-butane ($C_4F_9OCH_3$)

2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoropropane[$(CF_3)_2CFCF_2OCH_3$]

1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane ($C_4F_9OC_2H_5$)

2-(ethoxydifluoromethyl)-1,1,1,2,3,3,3-heptafluoropropane [$(CF_3)_2CFCF_2OC_2H_5$]

parachlorobenzotrifluoride (PCBTF)

methyl acetate

(B) Group II

methylene chloride (dichloromethane)

1,1,1-trichloroethane (methyl chloroform)

trichlorofluoromethane (CFC-11)

dichlorodifluoromethane (CFC-12)

1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)

1,2-dichloro-1,1,2,2-tetrafluoroethane (CFC-114)

chloropentafluoroethane (CFC-115)

cyclic, branched, or linear, completely methylated siloxanes (VMS)

tetrachloroethylene (perchloroethylene)*

ethylfluoride (HFC-161)

1,1,1,3,3,3-hexafluoropropane (HFC-236fa)

1,1,2,2,3-pentafluoropropane (HFC-245ca)

1,1,2,3,3-pentafluoropropane (HFC-245ea)

1,1,1,2,3-pentafluoropropane (HFC-245eb)

1,1,1,3,3-pentafluoropropane (HFC-245fa)

1,1,1,2,3,3-hexafluoropropane (HFC-236ea)

1,1,1,3,3-pentafluorobutane (HFC-365mfc)

chlorofluoromethane (HCFC-31)

1,2-dichloro-1,1,2-trifluoroethane (HCFC-123a)

1 chloro-1-fluoroethane (HCFC-151a)

*The listing of tetrachloroethylene (perchloroethylene) as a Group II Exempt Compound shall become effective December 2, 1997.

The use of Group II compounds and/or carbon tetrachloride may be restricted in the future because they are either toxic, potentially toxic, upper-atmosphere ozone depleters, or cause other environmental impacts. By January 1, 1996, chlorofluorocarbons (CFC), 1,1,1-trichloroethane (methyl chloroform), and carbon tetrachloride were phased out in accordance with the Code of Federal Regulation Title 40, Part 82 (December 10, 1993).

Whenever there is a conflict between the definition of exempt compounds of VOCs in this rule and the definition of exempt compounds of VOCs in another District rule, the definition in Rule 102 shall apply.

APPENDIX B

SOURCE TEST REPORT 02-193

CONDUCTED AT
CIWMB – Tierra Verde Ind.
7982 Irvine Blvd.
Irvine, CA 92618

(Prepared by South Coast Air Quality Management District)

AUDIT OF CIWMB FOR FIXED GASES AND VOLATILE ORGANIC COMPOUND (VOC) EMISSIONS AT A COMPOSTING OPERATION

TESTED: October 10, 2002

ISSUED:

REPORTED BY: Wayne A. Stredwick
Air Quality Engineer I

REVIEWED BY:

Michael Garibay
Senior Air Quality Engineer

MONITORING AND SOURCE TEST ENGINEERING BRANCH

MONITORING AND ANALYSIS

SUMMARY

a. Firm and Mailing Address ..... California Integrated Waste Management Board
1001 I Street
Sacramento, CA 95814

b. Site Location ..... Tierra Verde Ind.
7982 Irvine Ave., Irvine, CA 92618

c. Area Tested ..... Composting Test Piles

d. Test Requested by ..... Zorik Pirveysian, (909) 396-3133

e. Reason for Test Request ..... Information for Proposed Rule 1133

f. Date of Test ..... October 29, 2002

g. Source Test Performed by ..... Mike Garibay, Mei Wang, Wayne Stredwick

h. Test Arrangement Made Through…… Brenda Smyth, CIWMB, (916) 341-6605

RESULTS

Table 1 – Comparison of SCAQMD vs. CIWMB VOC Data

Sample	SCAQMD			CIWMB			% Difference of Total
	Tank	Trap	Total	Tank	Trap	Total	
Flux Chamber	70.0	22.0	92.0	<0.3	27.1	27.1	-71%
Audit Gas *	1145	317	1462	342	142	484	-67%

- * - Actual Audit Gas VOC Concentration was 1751 ppm.

Table 2 – Comparison of SCAQMD vs. CIWMB Fixed Gas Data
10/29/02-10/30/02

	CIWMB			SCAQMD		
Sample	% LEL	% O_2	% CO_2	% CH_4	% O_2	% CO_2
SPL1	5.0	4.0	18.4	<0.1	4.0	16.8
SPL2	7.0	1.8	21.8	<0.1	1.3	19.7
SPH1	5.0	12.9	6.8	<0.1	12.9	6.4
SPH2	5.0	12.2	7.4	<0.1	12.4	7.1
MPL1	19.0	1.9	21.6	0.9	1.6	21.6
MPL2	7.0	4.3	17.4	0.2	2.5	18.9
MPL3	9.0	4.5	16.6	0.3	4.7	15.9
MPH1	4.0	11.0	9.2	<0.1	10.9	8.9
MPH2	4.0	13.5	6.6	<0.1	13.1	6.4
MPH3	4.0	13.3	6.8	<0.1	12.9	6.6
MPL1(A)	4.0	16.3	4.6	<0.1	16.1	4.5
MPL2(A)	4.0	15.2	5.4	<0.1	15.2	5.1
MPL3(A)	4.0	14.7	6.0	<0.1	14.5	5.8
MPH1(A)	4.0	17.3	3.2	<0.1	16.9	3.1
MPH2(A)	4.0	17.5	2.8	<0.1	17.4	2.5
MKPH3(A)	3.0	16.5	3.8	<0.1	16.6	3.4

Table 3 – Comparison of SCAQMD vs. CIWMB Fixed Gas Data
11/6/02-11/7/02

	CIWMB			SCAQMD		
Sample	% LEL	% O_2	% CO_2	% CH_4	% O_2	% CO_2
SPL1	8.0	0.1	26.2	1.7	0.5	23.2
SPL2	15	0.6	26.0	2.1	1.7	22.5
SPL3	18	3.3	20.8	0.9	3.2	19.5
SPH1	6.0	10.2	9.4	<0.1	10.4	9.0
SPH2	6.0	11.7	7.8	<0.1	11.8	7.5
SPH3	6.0	16.1	3.4	<0.1	16.9	2.9
MPL1	8.0	0.3	23.6	5.3	0.6	22.9
MPL2	42	2.8	18.6	2.4	3.0	18.1
MPL3	9.0	0.4	28.6	8.8	0.4	27.4
MPH1	12.0	17.5	2.0	<0.1	18.3	1.6
MPH2	12.0	18.0	2.4	<0.1	17.7	2.0
MPH3	12.0	19.0	1.6	<0.1	18.7	1.2
MPL1(A)	14.0	7.8	9.6	0.4	8.9	8.8
MPL2(A)	12.0	11.2	7.4	0.1	11.2	7.1
MPL3(A)	14.0	7.8	9.0	0.8	8.2	8.5
MPH1(A)	11.0	15.8	3.6	<0.1	16.2	3.2

INTRODUCTION

On October 29, 2002, personnel from the South Coast Air Quality Management District (SCAQMD), conducted source tests at Tierra Verde Industries in Irvine, CA. The tests were intended to measure and compare emission concentrations of fixed gases (CO, CO2, O2, etc.) and VOC's on composting piles tested between the SCAQMD and the California Integrated Waste Management Board (CIWMB).

The testing was requested by the SCAQMD Planning Division in order to help in development of the Rule 1133 series (Emission Reductions from Composting and Related Operations). The CIWMB study was intended to investigate the emissions reduction potential of different aerated static pile composting techniques. The test presents a comparison of concentrations of fixed gases (CO, CO2, O2 etc..) and VOC as measured by the SCAQMD and CIWMB. The overall mass emission rates are calculated in the CIWMB report.

EQUIPMENT AND PROCESS DESCRIPTION

The experimental operation consisted of composting greenwaste with and without aeration and varying the Carbon/Nitrogen (C/N) ratio. Four compost piles were tested with the following configuration:

- Static Pile with high C/N ratio
- Static Pile with low C/N ratio
- Aerated Static Pile with high C/N ratio
- Aerated Static pile with low C/N ratio

The piles were tested over a one week period. The static piles were not touched during the week of testing. The aerated piles were tested before and after aeration with a Scarab machine.

The C/N ratio was varied by adjusting the ground wood (carbon) to leaf/grass (nitrogen) material ratios. The C/N ratio was increased by increasing the wood materials relative to the leaf/grass materials.

SAMPLING AND ANALYTICAL PROCEDURES

EPA Emission Isolation Flux Chamber

The procedure for measuring emissions from the compost pile surfaces is a modified form of the procedures found in the US Environmental Protection Agency's (EPA) *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber User's Guide.* The modifications are detailed in the following section.

Under the EPA procedures, gaseous emissions from surface migration are collected from an isolated surface area with an enclosure device called an emission isolation flux chamber. A sweep gas is introduced to the flux chamber at a fixed, controlled rate (5.0 lit/min recommended) as a carrier where it mixes with the contaminants from the surface migration. The flux chamber encompasses a fixed surface area (1.4 ft^2), and is designed to isolate the surface from phenomena that can influence the air surface interface such as wind speed, other meteorological conditions, or properties of the waste itself. The flux chamber is sunk to a depth of one inch into the surface in order to create a seal between the flux chamber and the surface. The flux chamber and sweep air system is designed such that the contents are well mixed and no internal stratification exists. A probe is located in the flux chamber to extract a gaseous sample for subsequent analysis. The probe is of such a design that the sample represents a composite of various altitudes from within the flux chamber. Sampling is conducted at a rate of lesser than or equal to the sweep air rate. The remainder of the flux chamber contents is allowed to vent through a small opening located strategically on the flux chamber dome. For measuring flux chamber internal temperature, a thermocouple is also located within the flux chamber.

Modifications to the Flux Chamber Method

The Flux Chamber procedure is intended primarily for surface migration from landfills, hazardous waste treatment facilities, and hazardous spill remediation covered under the RCRA and CERCLA acts. The procedure assumes that gaseous emissions from the surface within the chamber area are much less than that of the sweep air rate. Under this assumption, mass emissions of a given contaminant are a product of the measured sample concentration and sweep air rate and reported per unit of surface area. Upon field evaluation of the flux chamber, it was discovered that the surface flux migration rate was more appreciable for composting applications and could not be ignored as compared to the sweep air rate. The calculation of mass emissions of a given contaminant thus becomes a product of the measured sample concentration, sweep air rate, and surface migration rate. This surface migration rate would also include the effect of air entering the flux chamber due to wind induced leaks at the flux chamber to surface seal. Furthermore this migration rate could not be directly measured due to the discovery that any attempt to employ a measuring device resulted in impedance of the surface migration.

As an amendment to the EPA procedure, the surface migration rate must be determined in order to obtain accurate emissions measurements. A procedure for calculating surface migration employs a material balance and concentrations taken from the sample analysis of an inert known component initially mixed into the sweep gas (refer to material balance section).

The following sampling specifications were used during testing:

Sweep Air Mixture– 181 ppm CO
Sweep Air Rate - 5.0 lit/min

Modifications to the Flux Chamber Method (Con't.)

In order to account for general spatial variability, the flux chamber samples were drawn and integrated over several points around the piles for an averaging effect.

A small mixing fan is mounted within the flux chamber to ensure complete mixing within the flux chamber and allow for a homogeneous sample.

For this test, the flux chamber was operated by CIWMB's contractor Mr. Chuck Schmidt. Any questions on the design or operation of the flux chamber should be directed to Mr. Schmidt.

VOC by SCAQMD Method 25.3

Duplicate integrated gas samples were taken during each run using SCAQMD Method 25.3. The apparatus consisted of an 18 inch length of 0.125 inch o.d. Perfluoroalkoxy (also known as PFA, a type of Teflon) line for connection to a small glass impinger. The PFA tubing extended to the impinger tip as one continuous piece. The connecting tubing was not heated. Condensation was observed forming in this area during sampling due to the moisture present in the samples.

A small amount of hydrocarbon free de-ionized water was initially placed into the traps as a heat transfer medium. The impinger was immersed in an ice water bath with the outlet connected to a six liter summa polished canister as shown in Figure 3. The ice bath height was adjusted so that the water level did not exceed the level of any impinger connection as to avoid potential contamination. A constant sampling rate was maintained by using a small orifice flow controller. The impinger is of such a design that the impinger body also acts as a vial that can be capped and sealed before sampling and for sample storage. The sampling flow rate is driven by an initial 30 inches Hg vacuum in the canister and regulated by the constant flow controlling orifice. The flow controllers are designed and pre-tested to draw at a steady sampling rate from between the full 30 inches of vacuum down to 10 inches.

The sample canisters were checked for leaks by observing the internal vacuum gauges over a period of several hours. An observation of a zero loss in vacuum indicated an acceptable canister leak check. The remainder of the sampling apparatus was checked for leaks both before and after sampling by blocking the flow at the connector line end with a clean cap and introducing a portion of the tank vacuum into the remainder of the sampling system. An observation of the resulting cease in the gauge for a period of one minute indicated an acceptable leak check.

After the post-test leak check, the condensates present in the lines (not including the flux chamber lines) were rinsed into the impingers with hydrocarbon free water. This was accomplished by introducing a small amount of remaining tank vacuum to each line while dipping the open end of the line into the water of an extra sample vial. After a minimum of two separate one inch plugs of water were passed through the line and into the impingers, the lines were capped, sealed, and sent to the SCAQMD laboratory for purging.

Upon submittal of the samples to the laboratory for analysis, the canister pressures were obtained using a calibrated manometer. The canisters were then reassembled to the remainder of the sampling assemblies. The sample lines were connected to a source of ultra pure grade inert gas and introduced to a slight positive pressure at the ultra pure gas source. The sampling canister valves were opened and the pure gas was allowed to purge through the assemblies and into the canisters for a period of 10 minutes. The pure gas valves were closed and the lines depressurized before closing the canister valves to avoid back flushing the impinger assemblies. The glass vials were then disconnected, capped, sealed, and stored at approximately 35 ^{o}F until analysis.

The liquids within the impingers were analyzed with an infrared total carbon analyzer. The contents of the canisters were analyzed using SCAQMD Method 25.1 by the total combustion analysis (TCA) technique using a flame ionization detector (FID). Results were reported as the sum of those measured in the impingers and the canisters as Non-Methane Non-Ethane Organic Compounds (NMNEOC).

Compost Internal Temperature

Compost was monitored with a type "K" thermocouple at each sampling point. Results were reported as the temperature encountered approximately two feet below the surface at each location.

TEST CRITIQUE

The sample taken from the composted windrows was labeled SP3-2C/T-002 by the CIWMB contractor. The samples were taken over a continuous 60 minute period. Both the SCAP sample and the SCAQMD sample were simultaneously taken at the same point in the flux chamber. The SCAQMD VOC results were 71% higher than the CIWMB test result.

As a further check, an audit gas sampled was simultaneously sampled by the AQMD staff and the CIWMB contractor. A 1751 ppm TNMNEOC gas was analyzed by the AQMD laboratory and found to contain 1462 ppm TNMNEOC. The same gas analyzed by the CIWMB contracted laboratory found 484ppm TNMNEOC. The AQMD lab results were 67% higher for the audit gas than the CIWMB contracted laboratory.

Since the tests were taken simultaneously at the same sample point, it is assumed that the difference in results is from lab analysis. The lab used by SCAP for analysis has not been District approved for Method 25.3. The lab is working with the District to obtain certification.

For purposes of the CIWMB study; it is the conclusion of the audit test, that there is evidence of a low bias in the emissions as measured by the CIWMB study. It is interesting to note that the difference in results between labs was consistently high and similar in magnitude (67% & 71%).

Most of the VOC contribution in the SCAQMD samples was detected in the canister portion of the VOC analysis. Most of the discrepancy between the SCAQMD and CIWMB results occurred in the canister portion where many of the CIWMB canisters were non-detects. It is thought that perhaps the Method 25.3 back flush procedure was not detecting all of the VOC species present in the CIWMB samples. It is therefore recommended that this discrepancy be investigated prior to future analysis by the CIWMB contractor laboratory. For purposes of this test, it is thought that although the

CIWMB results reflect a large low bias, the results should be able to indicate the emission trends relative to the baseline due to the consistency of the bias.

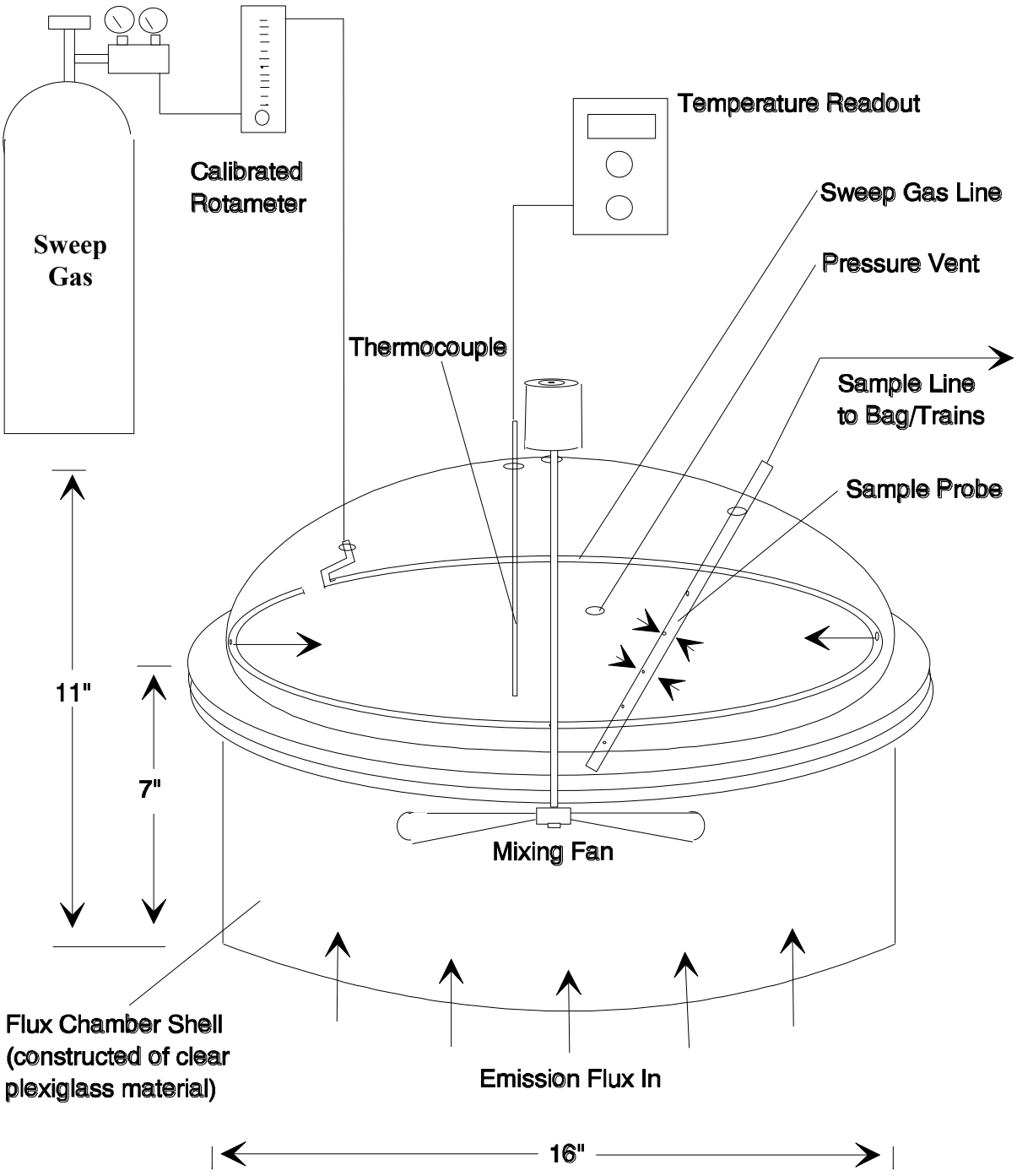


Figure 1 – Emission Isolation Flux Chamber (Not the actual one used for test)

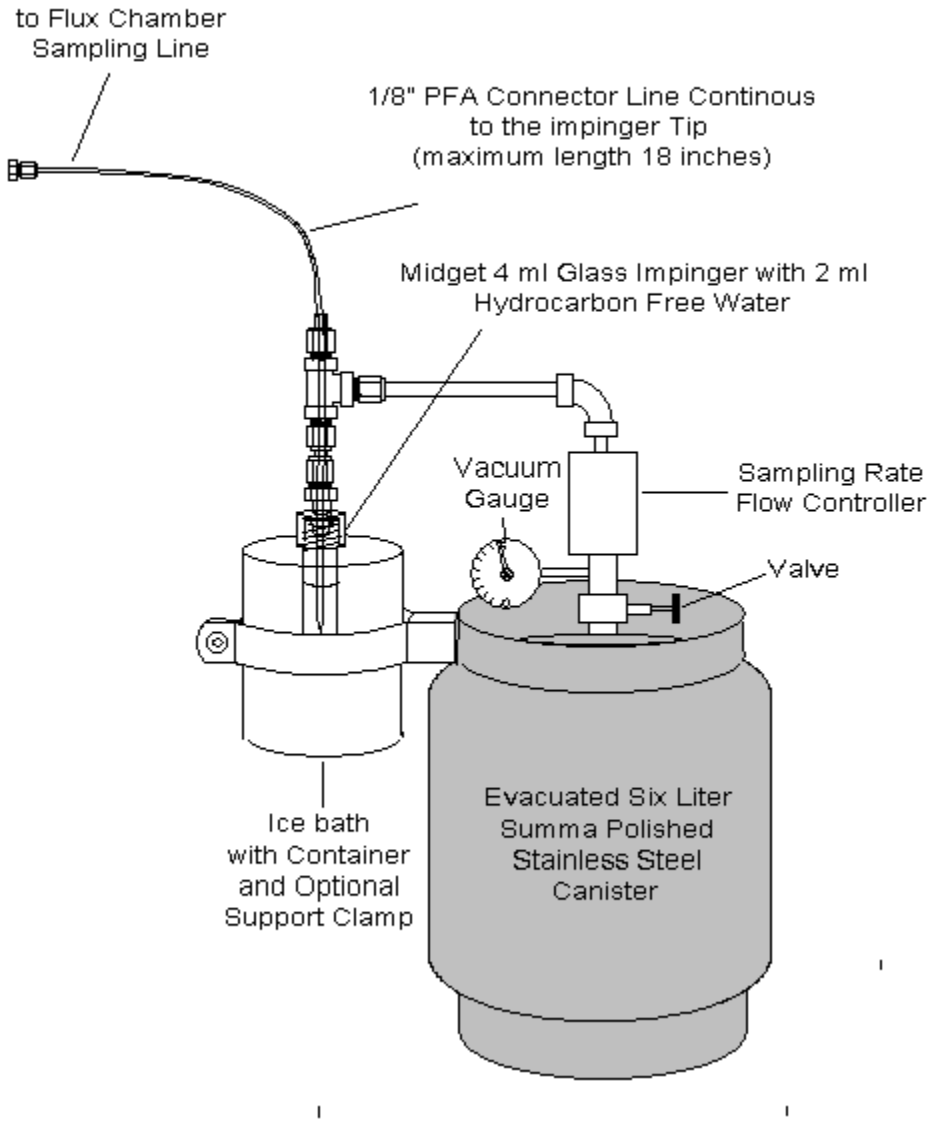
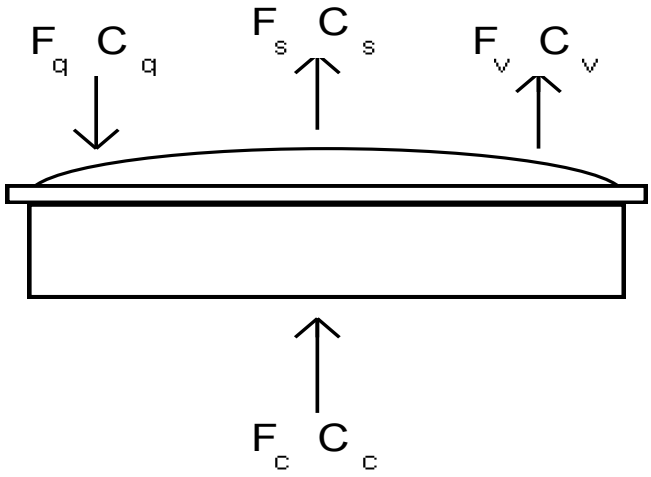


Figure 2 – VOC Sampling Apparatus

SOURCE TEST CALCULATIONS

Material Balance for Compost Surface Migration Rate

For calculating the compost surface migration rate, a CO material balance was performed around the flux chamber. CO was the chosen constituent because of inert properties and its ease of accurate analysis. The material balance is derived as follows:



Where:

F_g = Sweep Gas Flow Rate (measured)

C_g = Sweep Gas CO Concentration (analyzed)

F_S = Sample Flow Rate (measured)

C_S = Sample CO Concentration (analyzed)

F_V = Vent Flow Rate (unknown)

C_V = Vent CO Concentration (assume = C_s)

F_C = Compost Surface Migration Flow Rate (unknown and includes dilution air)

C_C = Compost Surface Migration CO Concentration (assumed zero)

Flow Balance:

$$F_V = F_C + F_g - F_S$$

Material Balance for Compost Surface Migration Rate (continued)

Helium Balance:

$$F_C C_C + F_g C_g = F_S C_S + F_V C_V$$

Substitute:

$C_C = 0$

$C_V = C_S$

F_V = Flow Balance

then:

$$F_g C_g = F_S C_S + (F_C + F_g - F_S) C_S$$

$$F_g C_g - F_C C_S = F_S C_S + F_g C_S - F_S C_S$$

$$F_c C_S = F_g C_g - F_g C_S$$

$$F_c = \frac{F_g(C_g - C_s)}{C_S}$$

APPENDIX C

TECHNICAL TABLES

This file contains a series of 12 spreadsheets reporting the actual emissions flux measurements made in the field during the study. This includes measurements made by the hand-held gas meter—referred to as an FID—as well as measurements from samples taken with the surface isolation flux chamber and sent to a laboratory for analysis using method 25.3.
The spreadsheets are not included in this document but can be downloaded from the CIWMB website.
The charts include measurements for odor and ammonia, as well as for volatile organic compounds (VOC). VOC are reported as TNMHC, which stands for total non-methane hydrocarbons. Emissions fluxes are reported in terms of pounds of gas emitted per square foot of windrow surface per hour.
This is not the same as an emissions factor, which reports gases in terms of pounds of gas per ton of feedstock.